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A SYSTEM FOR THE AXIAL LOADING OF CREEP SPECIMENS.(U)
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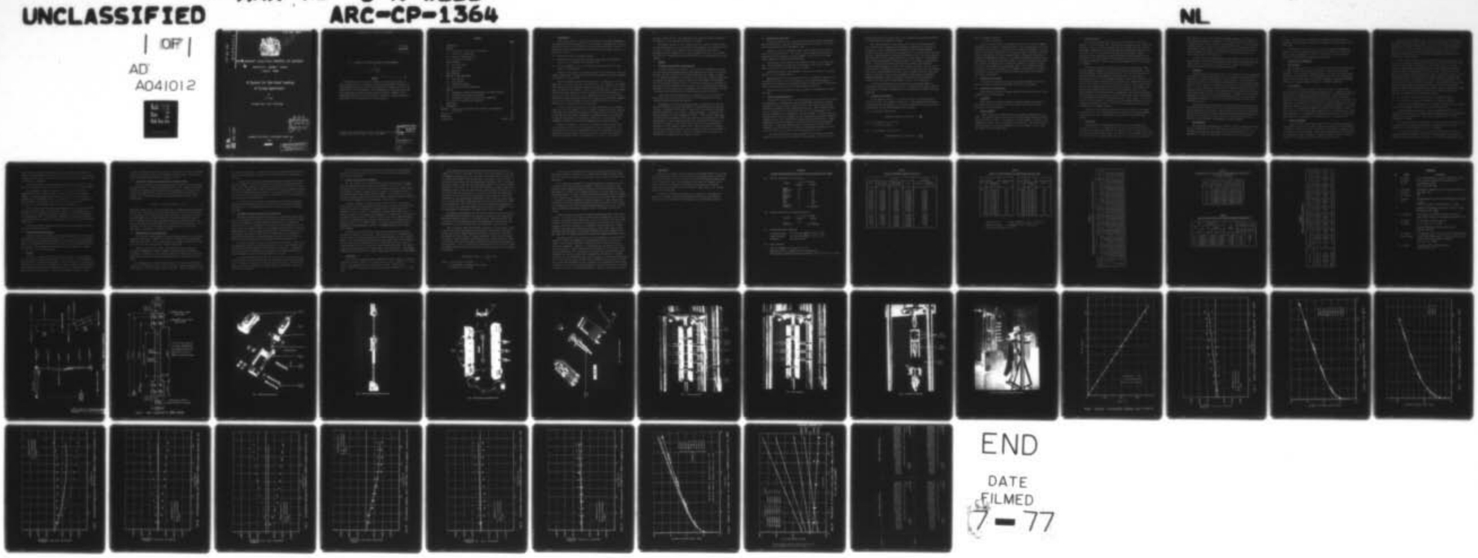

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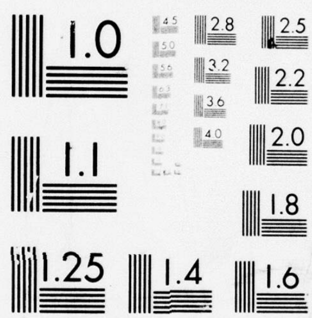
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CURRENT PAPERS

A System for the Axial Loading of Creep Specimens

by

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(6) A SYSTEM FOR THE AXIAL LOADING OF CREEP SPECIMENS.

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(9) Current papers,

SUMMARY

The problem of eccentricity of loading is considered in relation to tensile creep testing. An alignment system has been developed to provide for the measurement and correction of the eccentricity of loading relative to the centre line of the test specimen. The repeatability of creep test data using this system over a period of several years is reviewed. Comparison with deliberately malaligned tests indicates that axiality of loading contributes significantly to the repeatability of creep testing.

* Replaces RAE Technical Report 76043 - ARC 36895.

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CONTENTS

1 INTRODUCTION

When it was decided to initiate work on creep in Structures Department it was recognized that the feasibility of a creep research programme was critically dependent on the level of repeatability which could be achieved in practice. It was considered that a repeatability of ±5% in the time to a given strain was desirable in order to

(a) minimise the need for multiple testing,

(b) enable results from tests with different load, time, and temperature histories to be compared with confidence, and

(c) test the 'goodness of fit' of existing or new creep laws with a high degree of discrimination.

Studies of the results of nominally identical tests carried out within and between laboratories[1-4] showed that the above requirement was not being achieved in conventional creep testing.

Lack of repeatability was widely attributed to variability of material properties and in many cases this was probably true. For example, it was likely that creep properties in castings, forgings, extrusions, thick plate etc. would vary with depth and orientation. However the creep properties of highly worked sheet material were expected to be more uniform and lack of repeatability in this case was more likely to be due to inadequate control of test conditions. Preliminary testing on aluminium alloy sheet (Specification DTD 5070A) suggested that this was so and consequently work was started in 1963 to study ways of improving creep testing techniques and equipment.

A study of the known temperature and stress sensitivity of the material under test led to the adoption of more stringent tolerances than those required by BS 1686, the relevant British Standard for high sensitivity creep testing. No published work was found recommending a suitable tolerance for axiality of loading and consequently a tolerance was derived which was considered to be reasonably consistent with the chosen temperature and stress tolerances.

Axiality of loading to this level of accuracy could not be achieved by conventional means and it was found necessary to adopt a new approach. The system designed to meet these requirements consisted of adjustable universal joints which were attached to the ends of the test specimen and a measuring system which provided a means of determining the position of the specimen

relative to the load axis. The adjustment of the universal joints allowed for the correction of any initial non axiality of loading.

This Report reviews the use of this system over a period of several years of creep testing and it is concluded that the requirements for repeatability can be met on a routine basis. Results from a small number of deliberately malaligned tests are compared with correctly aligned tests and it is concluded that axiality of loading contributes significantly to the repeatability of creep testing.

2 GENERAL

2.1 Tolerance on stress due to non axiality

No direct evidence on the effect of non axiality of loading on creep test data had been found although experience had suggested that this factor could be important and most high sensitivity laboratories made some attempt to control it. BS 1686 also recognized its importance and stated that: "Special means shall be provided and precautions taken to ensure that the loading of the specimen shall be as nearly as possible axial." No quantitative advice was available on the sensitivity of creep data to this effect or to the tolerances which might be acceptable. In the absence of any recommendations it seemed reasonable to choose a tolerance which was consistent with temperature and stress tolerances.

To meet the overall requirement for a repeatability of ±5% on time to a given creep strain it was necessary that the error contributions from the individual factors should be much smaller.

Assuming that the three influencing factors of temperature, stress and specimen variability had equal significance, individual tolerances producing less than a ±3% effect were required. However due to the lack of knowledge on specimen repeatability it was decided to adopt tolerances on temperature and stress equivalent to a more stringent ±2% effect. From the known temperature sensitivity of the aluminium alloy being tested this was equivalent to $\pm 0.2^{\circ}C$. An examination of the relationship between the stress and the temperature to produce 0.1% strain in a given time indicated that $0.2^{\circ}C$ was approximately equivalent to 0.25% change in stress level. This latter value was therefore not only the tolerance required on overall stress but also on the uniformity of stress across the test section. Hence any bending stresses resulting from eccentricity of loading were also limited to ±0.25%.

2.2 Definition of terms used

It would be useful at this stage to define some terms used in this Report before considering non axiality of loading in more detail and Fig.1 illustrates the following definitions in diagrammatic form.

Load axis: The line through the test assembly along which the applied load can be considered to act. This line will pass through the centre of any low friction joint installed in the test assembly since joints of this type cannot transmit any significant bending moment.

Eccentricity: Any deviation of the specimen's centre line from the load axis. If the assumption is made that the specimen's centre line is straight then eccentricity can be sub-divided into two types:

Lateral eccentricity: The specimen's centre line is parallel to the load axis but is not coincident with it.

Angular eccentricity: The load axis crosses the specimen's centre line at an angle at the centre point of the specimen. In this Report the angular eccentricity is measured as the distance between the centre line of the specimen and the load axis at each end of the gauge length, see Fig.1c.

Any eccentricity existing will usually consist of a combination of these two types.

2.3 Review of accepted practice

Some work[5-7] had been done at room temperature on the eccentricity of loading associated with conventional creep testing machines showing that bending stresses of ±20% of the nominal stress level were not unusual unless methods specifically designed to limit eccentricity were used. These bending stresses were not predictable since they varied from test to test depending on the relative alignment of the components in the test assembly. The rigid control of manufacturing tolerances throughout the test assembly was one method proposed to minimize eccentricity. Unfortunately this was difficult particularly in high temperature creep testing where it could lead to the welding of mating parts under load. A progressive degradation of tolerances over a series of test assemblies could take place and in addition time dependent deformations could occur particularly in the case of the testing machine pull rods.

The second method which had been proposed was the fitting of universal joints at each end of the test specimen. This technique was valuable since if

defined the load axis at points close to the specimen but eccentricity relative to these points still remained a problem.

Most high sensitivity creep laboratories relied on tolerancing coupled with trial and error assembly using extensometer readings as an indication of eccentricity. The two independent extensometers used to measure specimen extension during the test were fitted symmetrically, one on each side of the test specimen. Room temperature loadings were carried out over a restricted range to test the quality of the assembly and to derive Young's modulus. Any difference between the two extensometer readings was taken to be evidence of eccentricity and if it exceeded some arbitrary tolerance the assembly was dismantled, components were exchanged or rotated and a further trial made. This trial and error sequence was repeated as necessary until an acceptable result was obtained. Unfortunately this technique would only control lateral eccentricity since pure angular eccentricity of any practical magnitude would produce no difference between extensometer readings. Secondly no information was provided about eccentricity in the plane at right angles to that of the extensometers.

It can be seen therefore that a satisfactory conventional method of eccentricity control did not exist and that no attempt had been made to specify an eccentricity tolerance compatible with the temperature and stress tolerances being used.

2.4 Eccentricity tolerance

It was argued in section 2.1 that the stress due to bending should be limited to ±0.25% of the nominal stress level. Simple bending theory provided the following two relationships to convert this requirement into an eccentricity tolerance for circular and rectangular cross sections.

(a) For circular cross sections

$$\text{maximum permissible eccentricity} = \frac{\sigma d}{800}$$

where d = diameter of test specimen

σ = % stress tolerance.

(b) For rectangular cross sections

$$\text{maximum permissible eccentricity} = \frac{\sigma d}{600}$$

where d = depth of section

σ = % stress tolerance.

The specimens used were of rectangular section cut from 16 swg (1.626mm) thick sheet with a width of 12.70mm (see Fig.2). The corresponding eccentricity tolerances using the above relationship were 0.0007mm and 0.0053mm in the thickness and width planes respectively. These were stringent requirements and while it was considered that the width tolerance might be attainable the thickness tolerance of 0.0007mm was clearly not. On further consideration however it was realized that the specimen was very flexible in the critical plane and would in fact approach the behaviour of a wire with the formation of plastic hinges at each end of the specimen outside the gauge length. It was therefore decided to specify an eccentricity tolerance of $\pm$0.005mm in both planes and to design an alignment system to achieve this which would also satisfy the following three major requirements.

(a) Definition of load axis

A low friction universal joint should be rigidly attached to each end of the test specimen to define the load axis relative to the specimen.

(b) Measurement of eccentricity

Means should be provided to measure specimen eccentricity relative to the centres of the universal joints.

(c) Adjustment

Means should be provided to adjust the specimen centre line relative to the centres of the universal joints in both planes so that any existing eccentricity could be corrected.

3 DESIGN FEATURES

Tensile creep tests on light alloy were required at temperatures up to 250°C. The specimens used were to British non-ferrous (BNF) design (see Fig.2) involving loads up to 5kN. It was however considered prudent to design for the maximum load capacity of the testing machines being used. Items exposed to the test environment were therefore designed for a load of 20kN (2 ton) at 250°C for times in excess of 50000 hours.

3.1 Universal joints

Low friction universal joints were required at each end of the test specimen to define the load axis. These joints were exposed to test conditions and the selection of a pivot system was the major problem. The low friction requirement suggested the use of knife edges and a considerable amount of work was carried out on the construction and testing of prototypes. However difficulties were experienced in meeting the maximum load requirement at the temperature level involved and also in the positive identification of the axis of rotation necessary to obtain eccentricity measurements within the tolerance of ±0.005mm.

Attention was therefore focused on an alternative design using 2.38mm (3/32in) diameter commercial needle rollers rotating in lapped grooves. These had a much greater load capacity within a given size than knife edges and the accuratelv ground surface provided a useful datum for the measurement of specimen eccentricity. The arrangement adopted is shown in Figs.3 and 4. Load was transferred from the machine pull rod through a ½in diameter BSF thread to the pull rod shackle. The specimen shackle was attached to the specimen using two bolts and clamping blocks to prevent relative motion. Both shackles were provided with lapped grooves and the load was transferred from one to the other through a central bearing block in compression. This block was provided with two grooves at right angles to each other and needle rollers were inserted in these grooves to provide the necessary rotation in two planes. Two rollers were used in each groove as a single roller of the required length could not be obtained from commercial sources. The joints were manufactured from S97 and cadmium plated to prevent corrosion.

Some initial difficulty was encountered due to corrosion in the lapped roller grooves but was overcome by plating the grooves in the central bearing block with nickel prior to lapping to provide a hard corrosion resistant surface.

3.2 Measurement

The measurement of specimen position relative to the load axis was achieved by the use of two measuring bars (see Fig.5) each fitted with four co-planar knife edges which contacted the appropriate set of needle rollers in the top and bottom universal joints. The position of the specimen at its centre and at each end of the gauge length was measured by three vernier micrometer

heads fitted to each bar and reading to 0.0025mm (0.0001in). The sensitivity for repeatable readings to this degree of accuracy was obtained by the use of a lamp and battery contact system for each micrometer head. Initial micrometer readings relative to the plane of the measuring bar knife edges were obtained on a graphite surface table. These were then corrected by the subtraction of half the needle roller diameter to provide the datum readings required to relate the specimen to the load axis.

In use the bars were suspended from a yoke clamped to the upper pull rod and were held in contact with the needle rollers by tension springs connecting the two units. They could be fitted to the test assembly in two planes to measure both specimen width and thickness eccentricity.

3.3 Adjustment

Having defined the load axis by the use of universal joints and determined the position of the specimen relative to it, the final design problem was the provision of a system of adjustments to obtain axiality. The correction of thickness eccentricity was obtained by the displacement of the specimen shackle along its roller relative to the bearing block and the other needle roller (see Fig.3). This was achieved by the use of four detachable differential screw adjusters (see Fig.6) clipped to the specimen shackle side plates and provided with movable probes to contact the bearing block. The sensitivity required was provided by a differential screw system operating the probe. Coarse initial adjustment was achieved by the use of one of the two screws required for the differential system.

In the other plane the correction of width eccentricity was obtained by the rotation of an eccentric built into the specimen shackle (see Fig.3) carrying the appropriate roller groove. This eccentric was rotated by an extension arm and screw system and could be locked in position when alignment was satisfactory. Both adjustments could be carried out with the measuring bars in position so that adjustment and measurement proceeded together.

4 TEST PROGRAMME

The creep research programme was intended to provide comprehensive creep-data on a single material over a wide range of varying stress histories. It included an investigation into anelastic recovery and the effects of time at temperature to study the significance and interactions of the processes

involved. It was decided to arrange this programme so that the degree of repeatability being achieved using the new techniques, could be assessed at an early stage.

For comparison with the typical tests from the research programme six additional tests with deliberate eccentricity were carried out, at the same nominal stress and temperature. Three of these were set up with lateral eccentricities and three with angular eccentricities.

5 DETAILS OF TEST PROCEDURES

5.1 Test specimen

The specimens were all cut in the direction of rolling from a single sheet of 1.63mm (16 swg) clad aluminium alloy sheet to Specification DTD 5070A (Appendix). They conformed to BNF design with a 114.3mm (4.5in) gauge length 12.7mm (0.5in) wide (Fig.2). Previous experience had shown that the specimen edges as machined were slightly curved and to eliminate the resulting bending effects these edges were ground straight to ±0.0038mm (0.00015in).

5.2 Test machines

Tests were conducted in eight 19.9kN (2 ton) capacity creep testing machines manufactured by Mand Precision Engineering Co. to RAE Specification and were located in a temperature controlled laboratory. The machines were fitted with 0.13m (5in) internal diameter ovens, 0.61m (24in) long. The heating element was divided into three separate zones. The output from an AEI Type RT3R temperature controller was fed to the three oven zones through three variacs for temperature gradient control. Loading was by deadweight through a 10:1 overhead lever beam. It was applied mechanically by the use of an electric variable speed screw jack to lower the weights required onto the loading pan in a smooth shock free manner. The load axis was adjusted to be vertical. The lever beam multiplying ratio was adjusted to be within ±0.25% of its nominal value.

5.3 Assembly procedures

It was considered that a small tension load was necessary throughout the test assembly even in the 'unloaded' condition to maintain relative alignments. A completely unloaded state was not possible as the weight of components below the specimen had to be supported. This standing load imposed on each specimen was therefore increased to produce a standard 'unloaded' stress of 2.76MN m^{-2} (400 lb in^{-2}) by adjusting the testing machine counter-balance.

Specimens were assembled to their universal joints in the testing machine leaving attachment bolts finger tight. New needle rollers were used for each test, bearing blocks were centralised by eye and a force of 890N (200 lb) was applied. This load was equivalent to a specimen stress of about 43.2MN m^{-2} (2.8 ton in^{-2}) and was maintained throughout the alignment procedure. The specimen attachment bolts were then tightened minimising bending stresses by balancing the torques applied.

The measuring bars were assembled to measure thickness eccentricity (see Fig.7). For consistent readings it was important to achieve rock free seating of the four knife edges on the universal joint needle rollers. This was obtained by holding the measuring bars firmly and rotating the test assembly through an angle of approximately $\pm 10^{\circ}$ several times. The location of the specimen was measured using the micrometer heads in conjunction with the surface plate datum readings. The calculated micrometer readings for alignment were set where possible on the appropriate micrometers and the differential screw adjusters were used until contact was obtained. The micrometers were retracted and the assembly lightly vibrated before taking a further set of readings. Additional adjustment and measurement were carried out until satisfactory alignment was achieved. In practice the tolerance of ±0.005mm (0.0002in) was difficult to achieve for the following two reasons:

(1) The resolution of the micrometer heads was 0.0025mm (0.0001in).

(2) The tolerance on specimen straightness was 0.0038mm (0.00015in).

It was therefore relaxed slightly to ±0.0076mm (0.0003in) giving a maximum stress due to bending of ±0.36% about the average stress level.

The measuring bars were removed, rotated through 90° and refitted to measure width eccentricity. The measurement and adjustment process was repeated using the eccentric adjusters to obtain width alignment within ±0.0076mm (0.0003in), see Fig.8.

The measuring bars were removed and the force was reduced to 445N (100 lb). This load level was maintained to minimise the possibility of accidental disturbance during the completion of the test assembly.

For tests with deliberate eccentricity the specimens were assembled employing the same techniques but using the alignment system to produce the lateral and angular eccentricities required. It should be noted however that a

lower load level of 445N (100 lb) was used during eccentricity adjustment to restrict the deflections resulting from the eccentric condition. All eccentric tests were carried out in the same testing machine using the same components and instrumentation throughout.

Two parallel motion creep extensometers[9] were used, one attached to each edge of the specimen using a simple jig to locate them and set the gauge length.

An incremental loading was carried out at the controlled laboratory temperature of 21°C, in order to check the function and quality of the test assembly. The load was applied in increments of 10N and the corresponding readings of both extensometers noted. An average value of Young's modulus was then determined. The maximum stress level was restricted to 55MN m^{-2} (3.6 ton in^{-2}) to avoid any possibility of plastic deformation.

Three miniature platinum resistance thermometers were attached to the test specimen at equal intervals along the gauge length. All thermometers were calibrated to ±0.1°C against three master thermometers at the test temperature to be subsequently used. Fig.9 shows the complete test assembly while Fig.10 is a more general view showing the testing machine and its associated illuminated scales unit.

A second incremental loading was carried out on each specimen, after the oven was positioned and packed.

5.4 Heating and loading procedures

During the first hour specimens were heated progressively to the required test temperature within a tolerance band of -5°C to +1°C. The test tolerance of ±0.2°C at all three thermometer positions was then achieved by suitable adjustments to the temperature controller and the three oven zone controls during the next 23 hours. The specimen was maintained within the temperature tolerance of ±0.2°C for the duration of the test.

6 RESULTS

The results available fall naturally into two groups. There are those from the current research programme which provide evidence of the repeatability being achieved with aligned test assemblies. This group consists of 28 tests all of which provide data on the repeatability of Young's modulus at room temperature. Ten of these were creep tested at 170MN m^{-2} and three at 108MN m^{-2} and provide evidence on the repeatability of creep strain measurement at 180°C. These

results are presented in sections 6.1 and 6.2 and provide the frame of reference required for the second group of deliberately eccentric tests. The results of this second group are presented in sections 6.3 and 6.4.

6.1 Incremental loading and determination of Young's modulus

Values of stress and strain obtained during a typical incremental loading are given in Table 1 and are shown graphically on Fig.11. Because of the high accuracy of the data a more sensitive method of examining the linearity and scatter was needed than the conventional stress/strain plot of which Fig.11 is typical. The technique devised was to evaluate deviations from the linear relationship:

$$\% \text{ strain} = \text{stress} \times 10^2/7.612 \times 10^4 \quad (1)$$

where the constant 7.612×10^4 is the mean value of Young's modulus derived from all 28 tests. The deviation of the strain data points from this relationship is shown graphically on Fig.12 again using the typical results given in Table 1. The individual values of Young's modulus for each test specimen are given in Table 2 together with the mean and standard deviation derived from them. It will be seen that the standard deviation is 0.076 which is equivalent to ±1% of the mean. All 28 results lie within two standard deviations of the mean resulting in a bandwidth of ±2% about the mean.

6.2 Repeatability of creep strain data

Ten creep tests were completed using as-received material at the nominally identical conditions of 170MN m^{-2} (11 ton in^{-2}) at 180°C for a minimum period under load of 96 hours. It was found possible to arrange at least one of these tests in each of the eight machines currently being used.

Values of total strain (elastic plus creep) at specific times up to 96 hours are summarized in Table 3 together with mean values and standard deviations. In addition, a representative selection of individual total strain data points from all ten tests are shown graphically, plotted against time on Fig.13.

An examination of standard deviations shows that they are approximately constant at 0.0016% strain up to a time of 25 hours. Standard deviations then rise slowly to a value of 0.0026% strain at 96 hours. This corresponds to 0.48%

of the mean total strain. All results lie within two standard deviations of the mean total strain giving a variation of ±1% when expressed as a percentage of the mean.

A further three tests in two testing machines were completed at the lower stress of $108 MN\ m^{-2}$ (7 ton in^{-2}) with all other conditions remaining constant. These results are presented in a similar form in Table 4 and on Fig.14 to those obtained at the higher stress level. It should be noted that standard deviations have not been evaluated since the number of tests available were too few but an examination of the data indicates that the repeatability is not inconsistent with that obtained in the previous tests.

It is interesting to note that the repeatability disclosed at time zero, immediately after the application of the test load is no different from that obtained later. The loading process itself has therefore proved to be highly repeatable.

6.3 Incremental loading of eccentric test assemblies

The values of Young's modulus derived from the incremental loading checks on the six deliberately eccentric test assemblies are given in Table 5, together with the test numbers and type and degree of eccentricity. The degree of angular eccentricity is specified as the deviation of the specimen centre line from the axis of loading at each end of the gauge length, see Fig.1c. With the gauge length of 114.3mm the angular eccentricities of 0.051mm and 0.127mm used are therefore equivalent to 0.05^{o} and 0.13^{o} respectively. The individual stress/strain data points are shown graphically on Figs.15 to 20 by plotting strain deviations from the linear relationship defined by equation (1).

The three laterally eccentric test assemblies, see Figs.15, 16 and 17 show the progressive growth in the difference between the left hand and right hand strains which would be expected from this type of eccentricity. In addition a significant amount of non-linearity is apparent at the largest eccentricity value and Young's modulus was not evaluated for this test.

The angular eccentricity results shown in Figs.18, 19 and 20 all exhibit small differences between the left hand and right hand strains and would therefore be accepted as aligned tests under conventional practice. At the largest angular eccentricity non-linearity is again apparent and Young's modulus was therefore not evaluated.

For both lateral and angular eccentricity the values of Young's modulus evaluated at the lower levels of eccentricity fall within the range obtained from the 28 aligned tests.

6.4 Creep of eccentric test assemblies

The six eccentric tests listed in Table 5 were creep tested for 96 hours under the nominally identical conditions of 170MN m^{-2} (11 ton in^{-2}) at 180°C. The measured values of total strain at various times during this loading period are presented in Table 6 together with the average of the aligned tests at corresponding times previously detailed in Table 3. In addition the two tests showing the greatest effect with 0.127mm (0.005in) lateral and angular eccentricities are shown compared with the basic creep curve on Fig.21.

In order to examine, in greater detail, the way in which the eccentric tests differ from the aligned tests the difference in total strain between each eccentric test and the average of the aligned tests is plotted against the appropriate times on Fig.22. An examination of these results shows that, in general, eccentricity increases creep deformation. The exceptions found were the two angular eccentricities of ±0.051mm (0.002in) which show a slight decrease, within two standard deviations from the aligned results. The highest value of angular eccentricity, ±0.127mm (0.005in), in contrast produced the greatest increase in creep deformation of 8.9% or 11 standard deviations at 96 hours after loading.

The lateral eccentricity test results present a more rational pattern. All show an increase in creep strain. Referring to Fig.22 it is apparent that the two tests at a lateral eccentricity of 0.051mm (0.002in) have very similar slopes and if a correction were made for the low initial total strain reading in test E4, then excellent agreement would be obtained indicating an increase in creep deformation of 3.1% or three and a half standard deviations. The higher value of lateral eccentricity, 0.127mm (0.005in) has resulted in an approximately proportional increase of 6.8% or eight standard deviations from the aligned data.

7 DISCUSSION

The 28 values of Young's modulus summarised in Table 2 exhibit a standard deviation of 0.076×10^4MN m^{-2} on the mean value of 7.612×10^4MN m^{-2}, i.e. a 1% effect. The highest and lowest values found of 7.763×10^4Mn m^{-2} and 7.474×10^4MN m^{-2} respectively lie within two standard deviations or ±2% of the mean.

The standard deviations obtained from ten constant load creep tests at 170MN m^{-2} (11 ton in^{-2}) and 180°C, see Table 3, rise from 0.0016% at zero time to 0.0026% after 96 hours on load. The mean total strain values at these times are 0.2502% and 0.5460%. Hence expressed as a percentage of the mean total strain the standard deviations are approximately constant at 0.5%. The highest and lowest values at time zero are within approximately two and a half standard deviations or +1.1% and -1.3%. The position at 96 hours is similar, again the highest and lowest values are within two and a half standard deviations or +1.1% and -0.4% of the mean total strain. It should be noted that the experimental results are in terms of strain at given times and are therefore not directly comparable with the repeatability requirement of ±5% on time to a given strain. The strain rate applicable at 96 hours for the condition of 170MN m^{-2} at 180°C is in the region of 1.85×10^{-3}% $hour^{-1}$ and the corresponding requirement on total strain at this time would therefore be in the order of ±0.0088% or 1.61% when expressed as a percentage of the mean total strain of 0.5460%.

The degree of repeatability and low scatter achieved in the above results is considered highly satisfactory and provides assurance that all significant factors are being controlled in a consistent manner. Some assessment of the contribution of the alignment system to this repeatability may be made by the examination of the data available from the deliberately eccentric tests.

The cold modulus checks show broadly the pattern one would expect, lateral eccentricities exhibiting substantial differential strain values (difference between left hand and right hand measured strains) and angular eccentricities showing the low values typical of aligned specimens. However when we examine the values of the differential strain obtained in the lateral tests and compare them with the values one would expect from simple bending theory discrepancies become apparent. Table 5 compares actual differential values with those derived from simple bending theory for a specimen of rectangular cross section using the relationship:

$$\text{differential strain} = 12e \frac{w}{d^2} \times 100\%$$

where e = eccentricity of loading

w = extensometer attachment width (10.2mm)

d = specimen width (12.7mm).

A whole range of differential strain results varying from 53% less than predicted to 39% more was obtained. In addition the 0.127mm (0.005in) lateral test also exhibited considerable non-linearity. Thus a variety of effects need explanation.

It is felt that a combination of specimen deflection, gravitational and frictional effects may have been responsible. Certainly the weight of the eccentric items comprising specimen, universal joints and extensometry formed approximately one third of the standing load level, the datum condition for the cold modulus check. At these low loads one would have expected the test assembly to move sideways and to rotate under the action of the eccentric moment leading to a condition of mixed angular and lateral eccentricity. These effects when coupled with friction and specimen deflection could have formed a complex condition changing with load level and incorporating random effects, and it is therefore not surprising that simple bending theory is inadequate to explain the results.

Creep testing of the eccentric assemblies produced generally larger total strains. In the case of the lateral eccentricities the magnitude of the effect is seen to be approximately proportional to the eccentricities used, the 0.127mm (0.005in) eccentricity producing a 6.8% increase in creep strain at 96 hours. Angular eccentricities resulted in an anomalous situation where the ±0.127mm (0.005in) value produced the greatest increase in creep strain found, an 8.9% effect whereas both tests at the ±0.051mm (0.002in) value fell slightly below the creep curve for aligned specimens but within two standard deviations from it.

Further work could be carried out in the investigation of eccentricity of loading to clarify the anomalies and uncertainties existing in the limited number of tests reported and also to extend the data to other conditions of stress and temperature. However it is considered that the primary objectives have been achieved. Tensile creep tests with a deliberate eccentricity of loading have demonstrated that eccentricity is a significant factor affecting the repeatability of creep data and should therefore be controlled to a tolerance consistent with the requirements for overall accuracy. In the tests reported here it is clear from the results, Fig.22, that for high precision data the tolerance should be 0.013mm (0.0005in) to limit the effect to one standard deviation; this corresponds to a ratio of eccentricity/depth of section of 0.001, and the current eccentricity tolerance of 0.0076mm (0.0003in) is therefore considered realistic.

8 CONCLUSIONS

Deliberately eccentric tensile creep tests have demonstrated that for high-precision repeatable creep data, eccentricities of loading should be limited to an eccentricity/depth of section value of 0.001 for rectangular specimens under the test conditions used. The conventional trial and error assembly used in creep testing is not capable of achieving this requirement since angular eccentricities and eccentricities in the plane at right angles to the extensometry are not detectable.

The positive alignment system which is the subject of this Report has proved to be capable of achieving consistently the eccentricity tolerance specified and is justified by the high quality of the creep data produced.

Appendix

EXTRACT FROM SPECIFICATION DTD 5070A FOR CLAD ALUMINIUM ALLOY SHEET

(a) Chemical composition of core material:

Element	Per cent by weight	
	Minimum	Maximum
Copper	1.8	2.7
Magnesium	1.2	1.8
Silicon	-	0.25
Iron	0.9	1.4
Manganese	-	0.2
Nickel	0.8	1.4
Zinc	-	0.1
Lead	-	0.05
Tin	-	0.05
Titanium	-	0.2
Aluminium	-	the remainder

(b) Chemical composition of cladding materials:

Element	Per cent by weight	
	Minimum	Maximum
Zinc	0.8	1.2
Aluminium	-	the remainder

(c) Minimum mechanical properties:

0.1% proof stress	not less than 308MN m^{-2} (20 ton in^{-2})
Tensile strength	not less than 386MN m^{-2} (25 ton in^{-2})
Elongation	not less than 6%

(d) Heat treatment:

Solution treatment by heating at 530 $\pm 5^{\circ}$C.

Quench in water at a temperature not exceeding 40°C.

Precipitation treatment by heating uniformly at 190 $\pm 5^{\circ}$C for 10 to 30 hours.

Table 1

TYPICAL INCREMENTAL LOADING TEST: RE 16

Stress $MN\ m^{-2}$	% strain			Linear relationship
	Left-hand extensometer	Right-hand extensometer	Mean	% strain = $\frac{\text{stress}}{7.612 \times 10^2}$
0	0	0	0	0
4.28	0.0055	0.0054	0.00545	0.0056
8.57	0.0109	0.0115	0.0112	0.0113
12.85	0.0165	0.0171	0.0168	0.0169
17.13	0.0221	0.0230	0.02255	0.0225
21.41	0.0278	0.0287	0.02825	0.0281
25.70	0.0337	0.0346	0.03415	0.0338
29.98	0.0392	0.0403	0.03975	0.0394
34.26	0.0451	0.0458	0.04545	0.0450
38.54	0.0508	0.0517	0.05125	0.0506
42.83	0.0565	0.0573	0.0569	0.0563
47.11	0.0622	0.0630	0.0626	0.0619
51.39	0.0679	0.0688	0.06835	0.0675
42.83	0.0566	0.0573	0.05695	0.0563
34.26	0.0453	0.0462	0.04575	0.0450
25.70	0.0339	0.0346	0.03425	0.0338
17.13	0.0225	0.0232	0.02285	0.0225
8.57	0.0113	0.0115	0.0114	0.0113
4.28	0.0058	0.0058	0.0058	0.0056
0	0	-0.0001	-0.00005	0

Table 2

VALUES OF YOUNG'S MODULUS (E) FROM AXIALLY ALIGNED TESTS

Test No.	M/C No.	E $\frac{MN\ m^{-2}}{10^4}$	% differential strain
RE 4	4	7.598	0.4%
7	3	7.763	0.3
8	7	7.763	0.3
9	3	7.681	0.5
10	4	7.612	1.4
11	6	7.543	3.3
12	1	7.632	1.3
13	6	7.522	1.1
14	2	7.570	0.6
15	2	7.584	4.8
16	5	7.495	1.4
17	4	7.557	1.5
18	1	7.653	1.7
19	8	7.736	0.9

Test No.	M/C No.	E $\frac{MN\ m^{-2}}{10^4}$	% differential strain
RE 20	4	7.660	1.9%
21	4	7.653	0.4
22	3	7.570	1.5
23	8	7.632	0.8
24	4	7.646	1.3
25	7	7.612	0.5
26	1	7.577	0.1
28	5	7.529	1.0
29	6	7.474	1.2
31	2	7.584	0.9
32	7	7.701	0
33	8	7.501	0.4
35	2	7.591	1.0
36	8	7.612	1.9

Mean value of E = 7.612×10^4 MN m^{-2} (11.04×10^6 lb in^{-2})

Standard deviation = 0.076MN m^{-2} (0.11×10^6 lb in^{-2})

Laboratory temperature = 21 $\pm 1^{\circ}$C

Table 3

REPEATABILITY OF TOTAL STRAIN IN CREEP TESTS AT: 170MN m^{-2} (11 ton in^{-2}) AT 180°C

Time hours	Total strain % (elastic + creep)											Standard deviation
	RE 7	RE 8	RE 11	RE 13	RE 14	RE 16	RE 19	RE 21	RE 26	RE 29	Mean	
0	0.2470	0.2496	0.2498	0.2504	0.2530	0.2518	0.2503	0.2486	0.2508	0.2511	0.2502	0.0016
0.1	0.2711	0.2756	0.2747	0.2762	0.2767	0.2763	0.2753	0.2730	0.2756	0.2749	0.2749	0.0016
0.25	0.2803	0.2845	0.2836	0.2849	0.2851	0.2851	0.2841	0.2815	0.2847	0.2828	0.2837	0.0016
1.0	0.2970	0.3018	0.3001	0.3023	0.3021	0.3018	0.3009	0.2988	0.3012	0.3008	0.3007	0.0016
2.6	0.3138	0.3190	0.3164	0.3185	0.3187	0.3180	0.3170	0.3152	0.3186	0.3174	0.3173	0.0016
10	0.3520	0.3565	0.3546	0.3558	0.3564	0.3551	0.3544	0.3527	0.3559	0.3549	0.3548	0.0014
25	0.3979	0.4016	0.3993	0.4012	0.4017	0.3992	0.4004	0.3974	0.4003	0.3999	0.3999	0.0014
48	0.4499	0.4538	0.4518	0.4518	0.4541	0.4511	0.4542	0.4496	0.4521	0.4528	0.4521	0.0016
72	0.4984	0.5020	0.5005	0.4992	0.5027	0.4994	0.5038	0.4971	0.4998	0.5025	0.5005	0.0021
96	0.5439	0.5471	0.5457	0.5445	0.5479	0.5449	0.5518	0.5420	0.5446	0.5480	0.5460	0.0026

Table 4

REPEATABILITY OF TOTAL STRAIN IN CREEP TESTS AT: 108.11MN m^{-2} (7 ton in^{-2}) AT 180°C

Time hours	Total strain % (elastic + creep)			
	RE 15	RE 31	RE 32	Mean
0	0.1548	0.1544	0.1534	0.1542
0.1	0.1618	0.1610	0.1603	0.1610
0.25	0.1650	0.1643	0.1632	0.1642
1.0	0.1719	0.1714	0.1699	0.1711
2.6	0.1787	0.1777	0.1771	0.1778
10	0.1925	0.1927	0.1924	0.1925
25	0.2083	0.2086	0.2076	0.2082
96	0.2457	0.2473	0.2465	0.2465

Table 5

VALUE OF YOUNG'S MODULUS (E) FROM ECCENTRIC TEST ASSEMBLIES

Test No.	Eccentricity			E $\frac{MN\ m^{-2}}{10^4}$	Differential strain at maximum stress	
	Type	Degree			Actual	Predicted
		mm	in			
E 1	Lateral	0.0127	0.005	Non linear	4.5%	9.6%
E 4	Lateral	0.0051	0.002	7.595	3.6%	3.8%
E 5	Lateral	0.0051	0.002	7.613	5.3%	3.8%
E 2	Angular	±0.0127	±0.005	Non linear	0.9%	0
E 3	Angular	±0.0051	±0.002	7.578	1.6%	0
E 6	Angular	±0.0051	±0.002	7.563	0.7%	0

Table 6

CREEP OF ECCENTRIC TEST ASSEMBLIES

Eccentricity	Test No.	Total strain % (elastic + creep) at times (hour) of:									
		0	0.1	0.25	1.0	2.6	10	25	48	72	96
0.127mm lateral	E 1	0.2507	0.2759	0.2850	0.3028	0.3200	0.3594	0.4067	0.4631	0.5222	0.5666
0.051mm lateral	E 4	0.2453	0.2706	0.2792	0.2965	0.3131	0.3507	0.3971	0.4514	0.5076	0.5496
0.051mm lateral	E 5	0.2496	0.2747	0.2835	0.3002	0.3170	0.3556	0.4020	0.4561	0.5131	0.5556
0.127mm angular	E 2	0.2526	0.2773	0.2865	0.3042	0.3216	0.3618	0.4107	0.4687	0.5287	0.5746
0.051mm angular	E 3	0.2485	0.2738	0.2827	0.2995	0.3159	0.3525	0.3976	0.4484	0.5010	0.5402
0.051mm angular	E 6	0.2500	0.2743	0.2826	0.2991	0.3151	0.3520	0.3964	0.4478	0.5035	0.5409
Mean of aligned tests from Table 3	-	0.2502	0.2749	0.2837	0.3007	0.3173	0.3548	0.3999	0.4518	0.5061	0.5460

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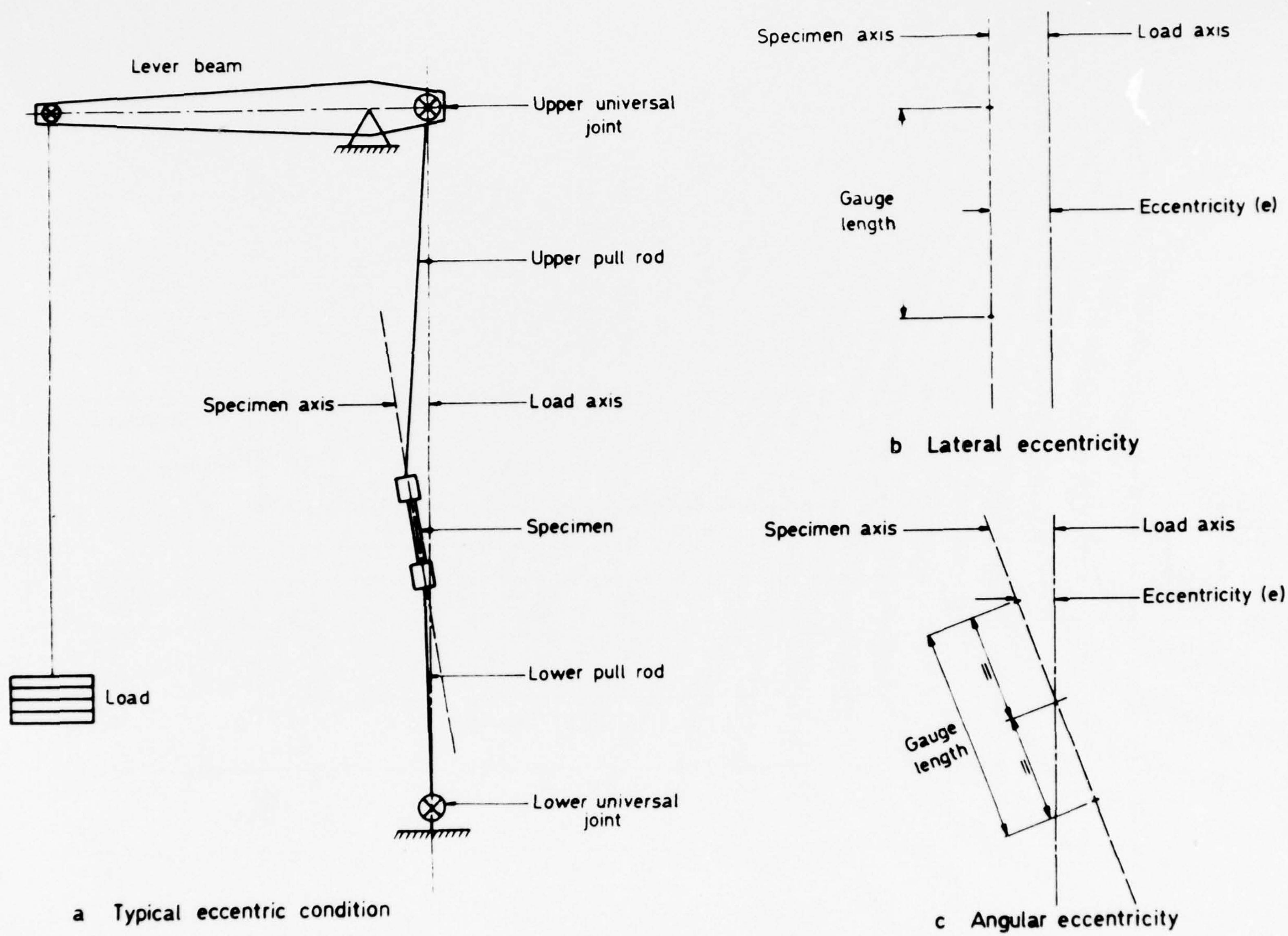

Fig.1a-c Definition of eccentricity

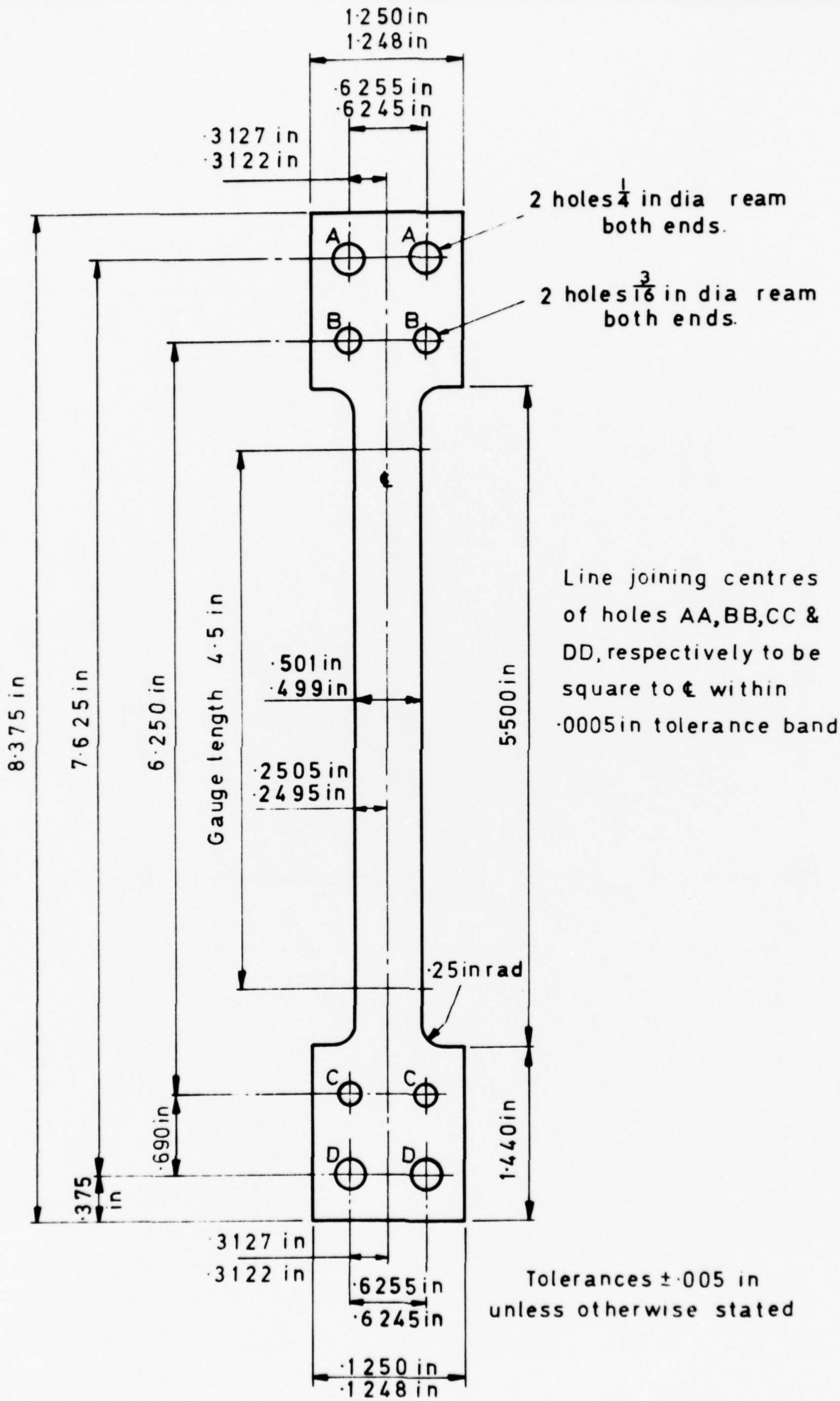

Fig. 2 Test specimen of BNF design.

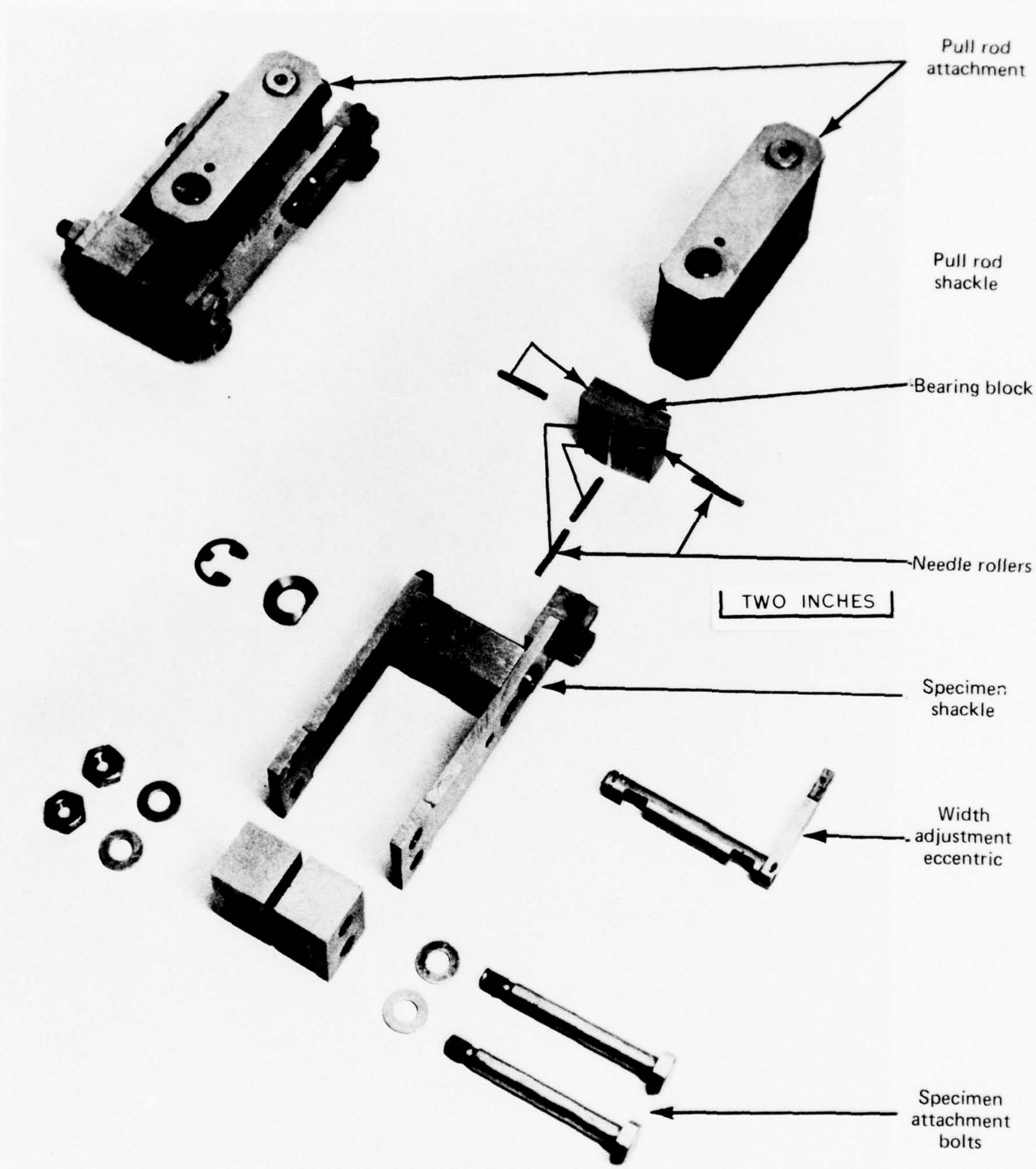

Fig.3 Universal joint construction

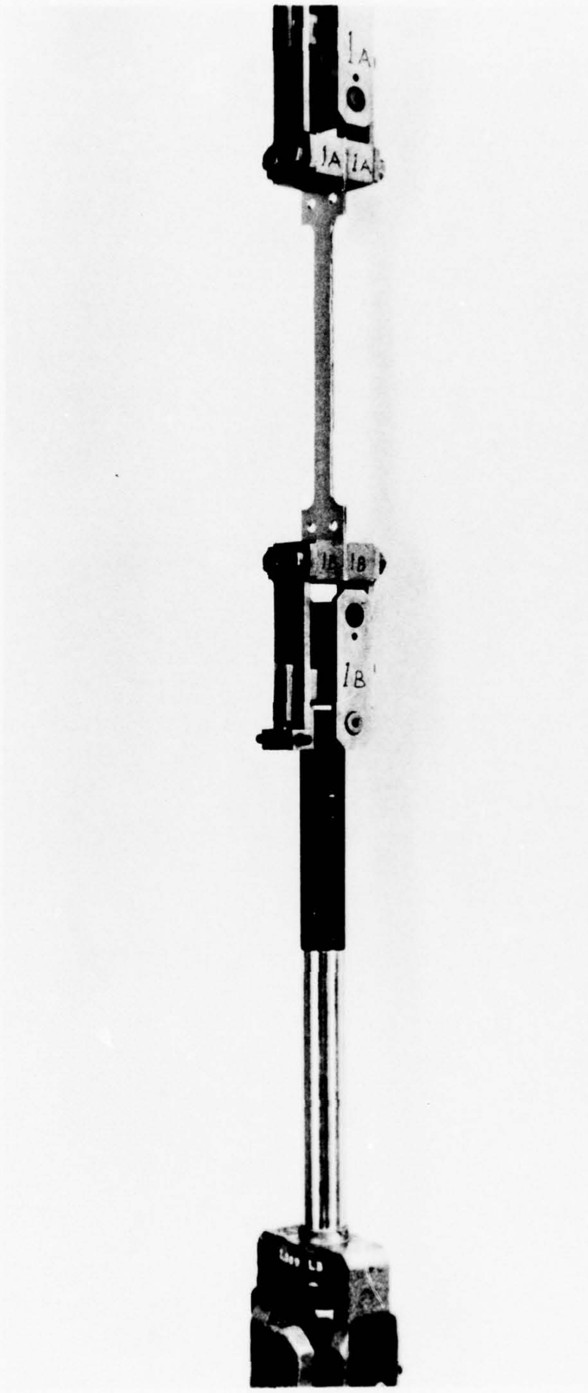

Fig.4 Universal joints and specimen assembly

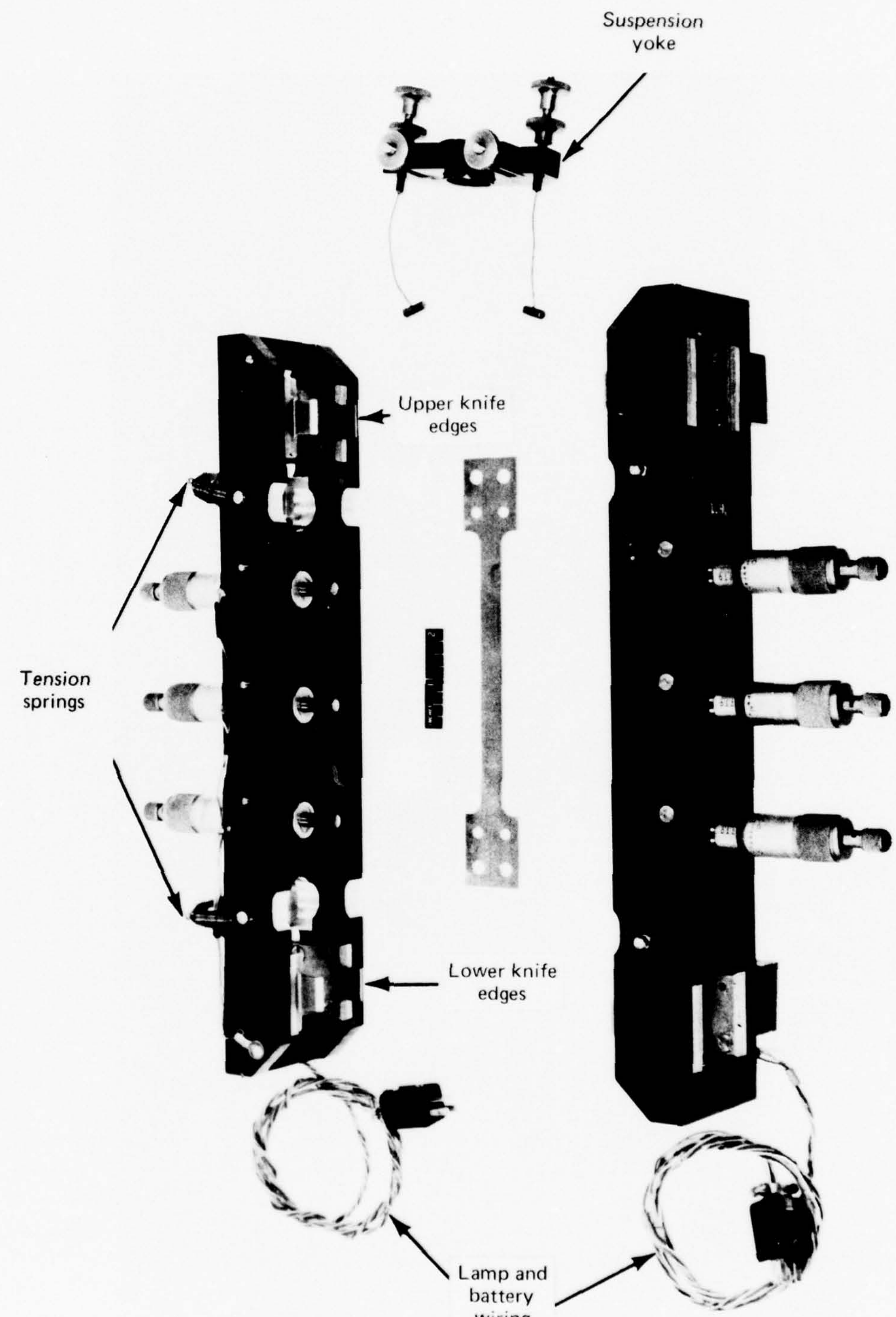

Fig.5 Measuring bars and suspension yoke

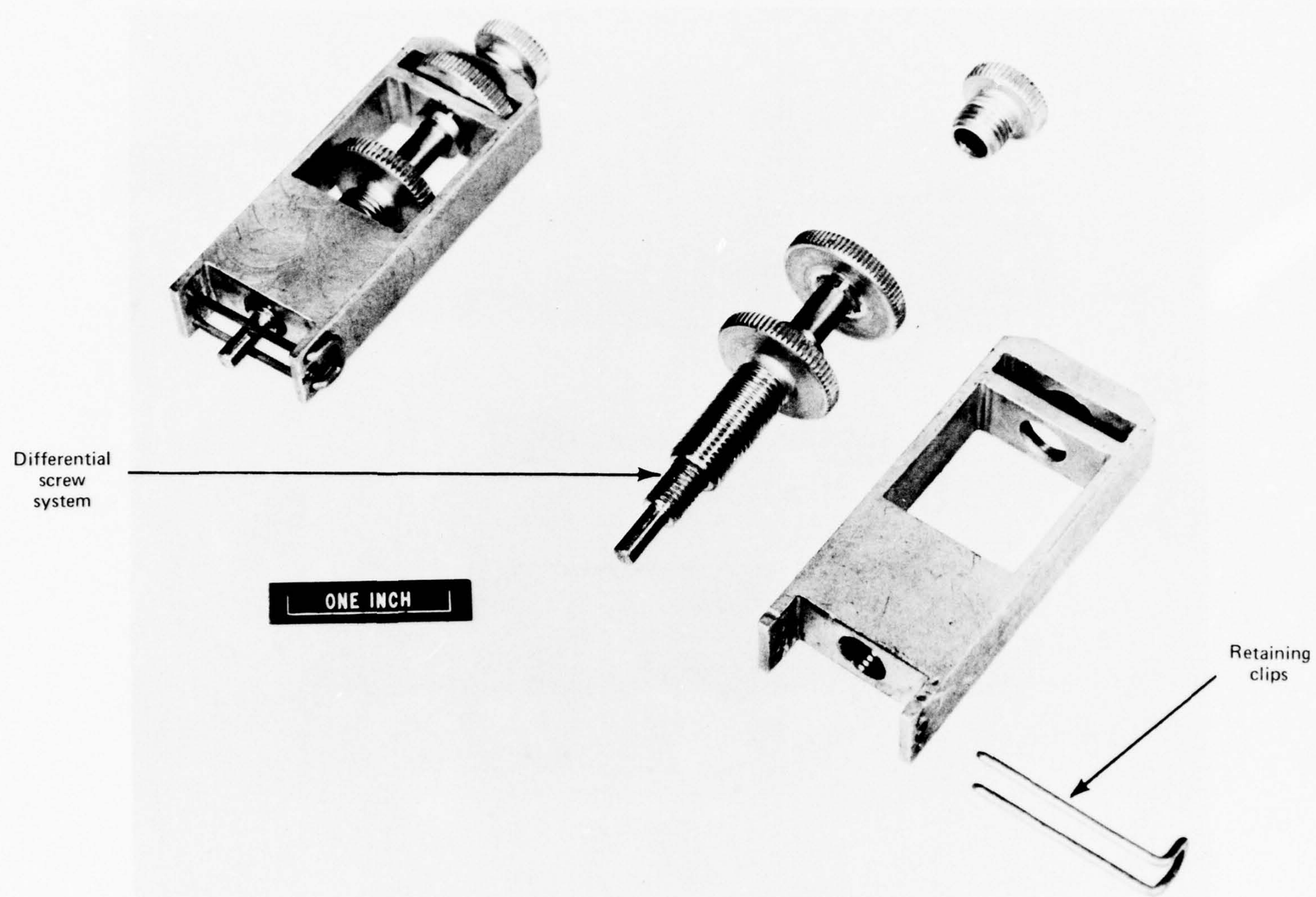

Fig.6 Differential screw adjuster

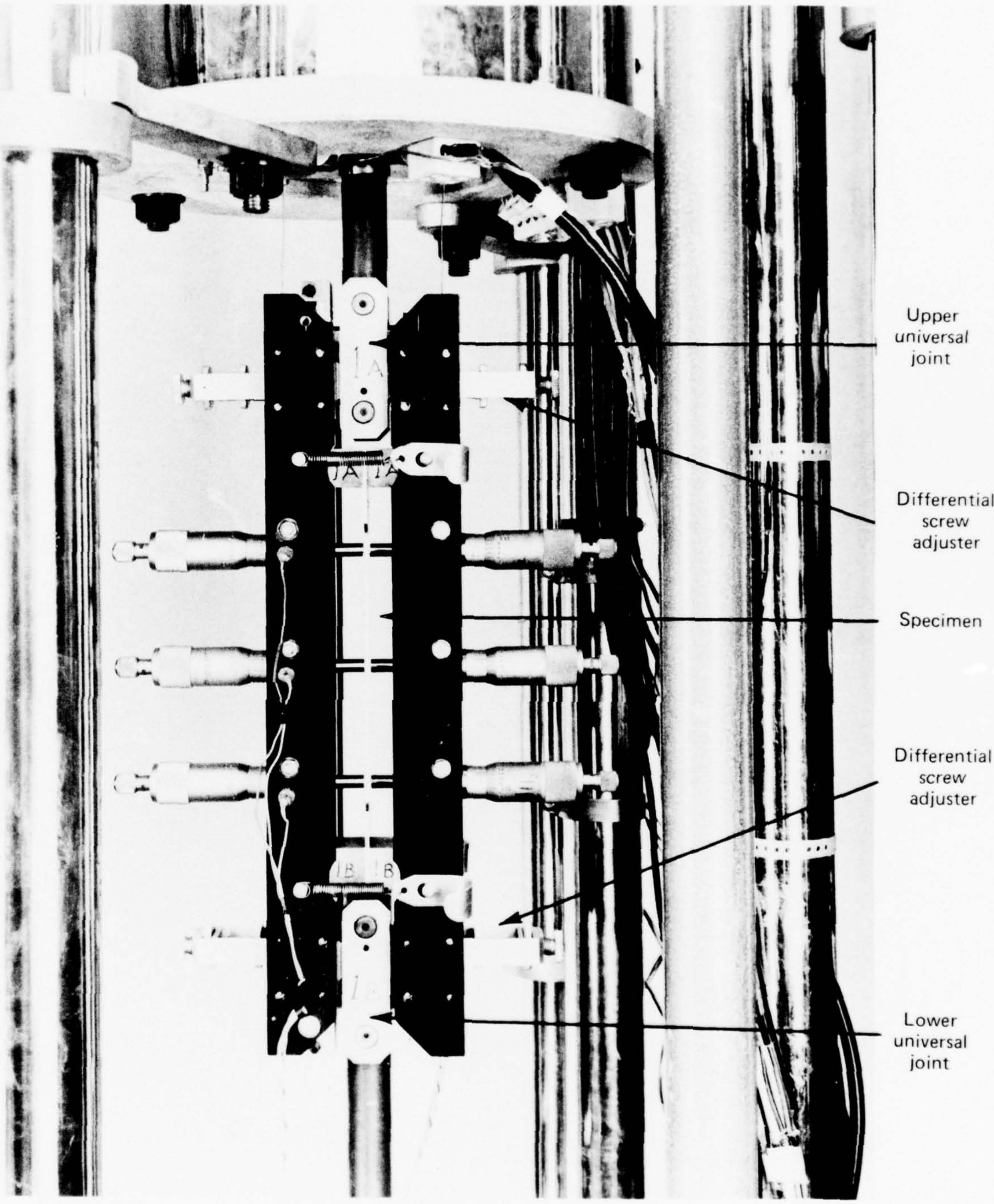

Fig.7 Thickness alignment

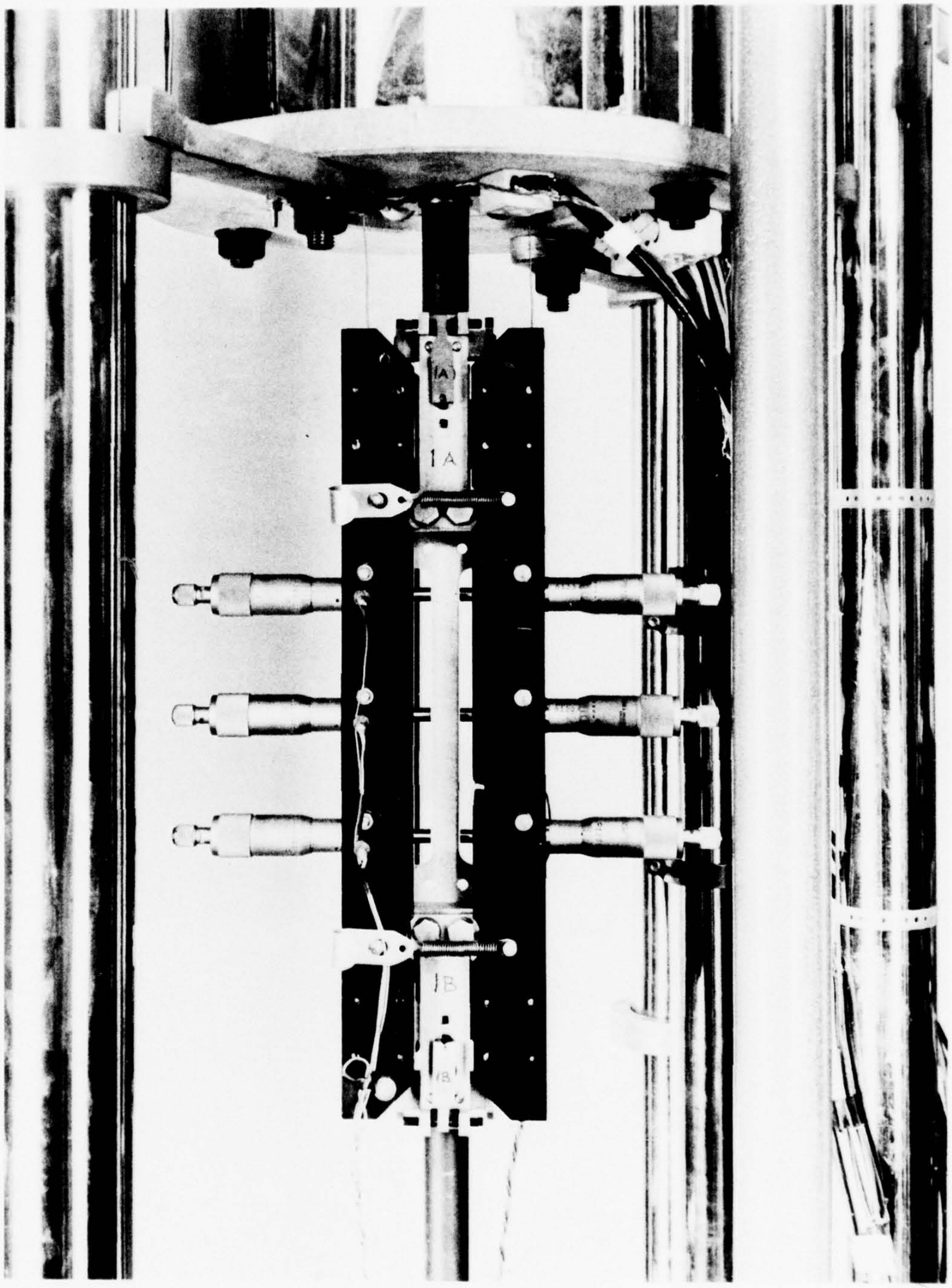

Fig.8   Width alignment

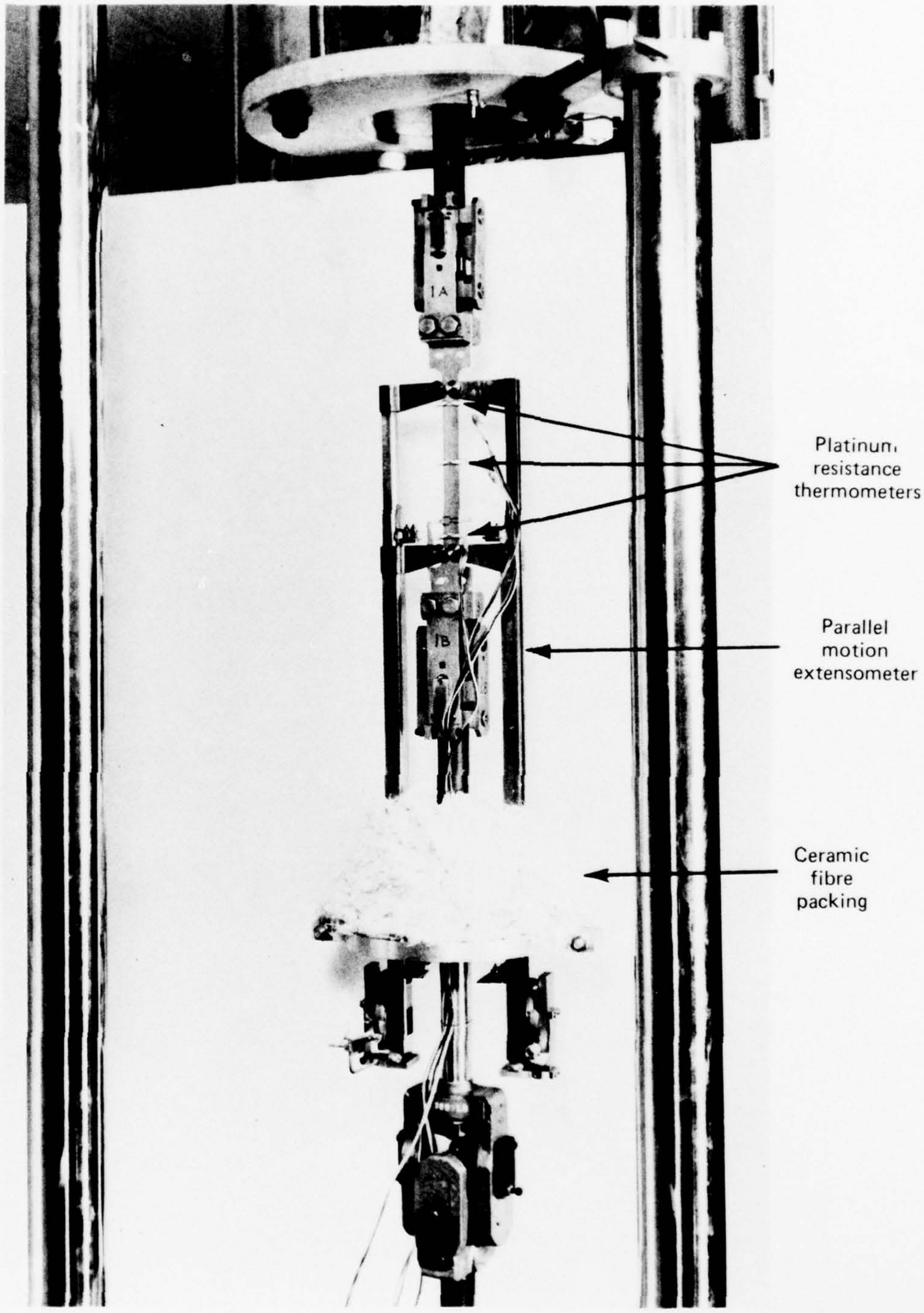

Fig.9 Completed test assembly

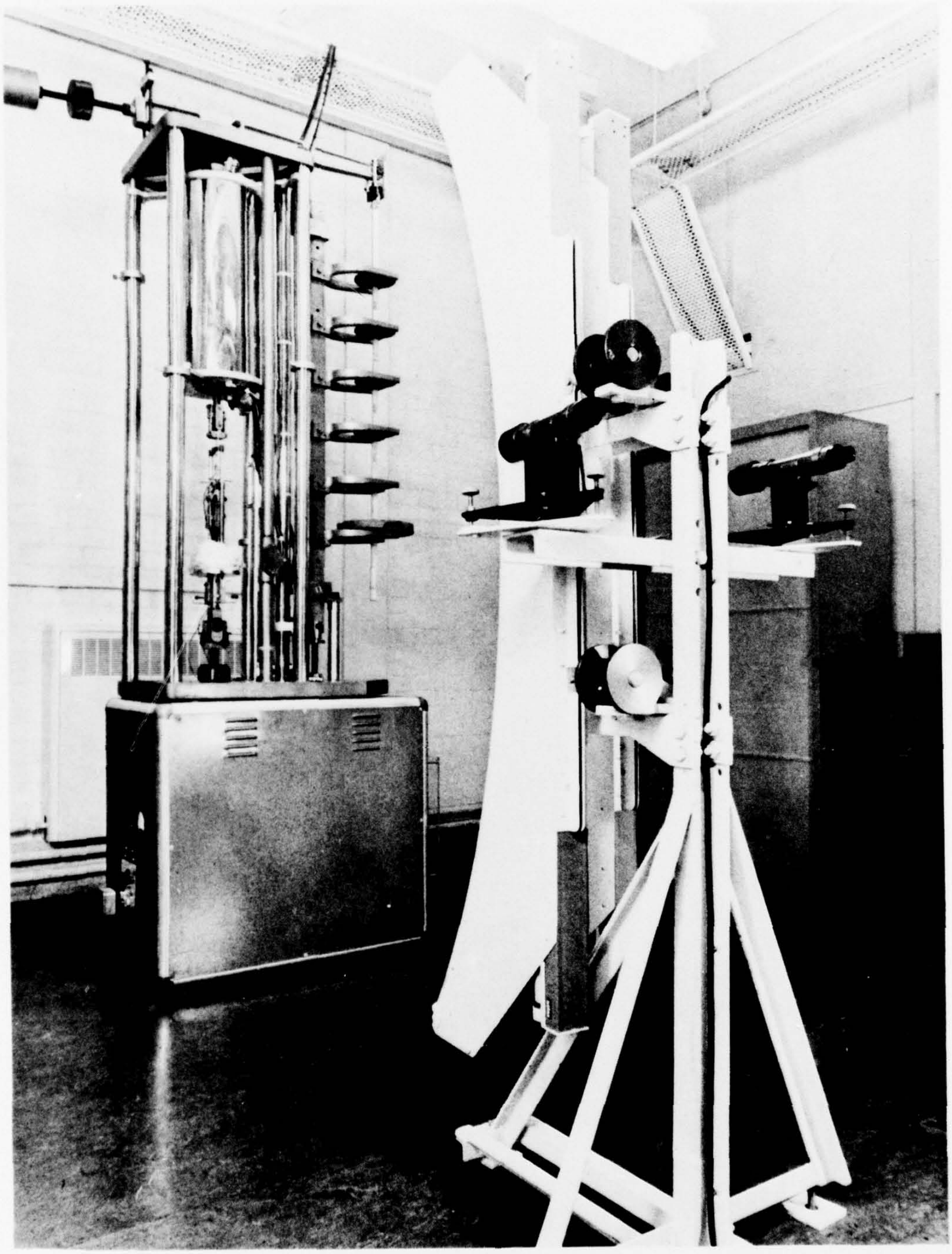

Fig.10 Test assembly, machine and scale unit

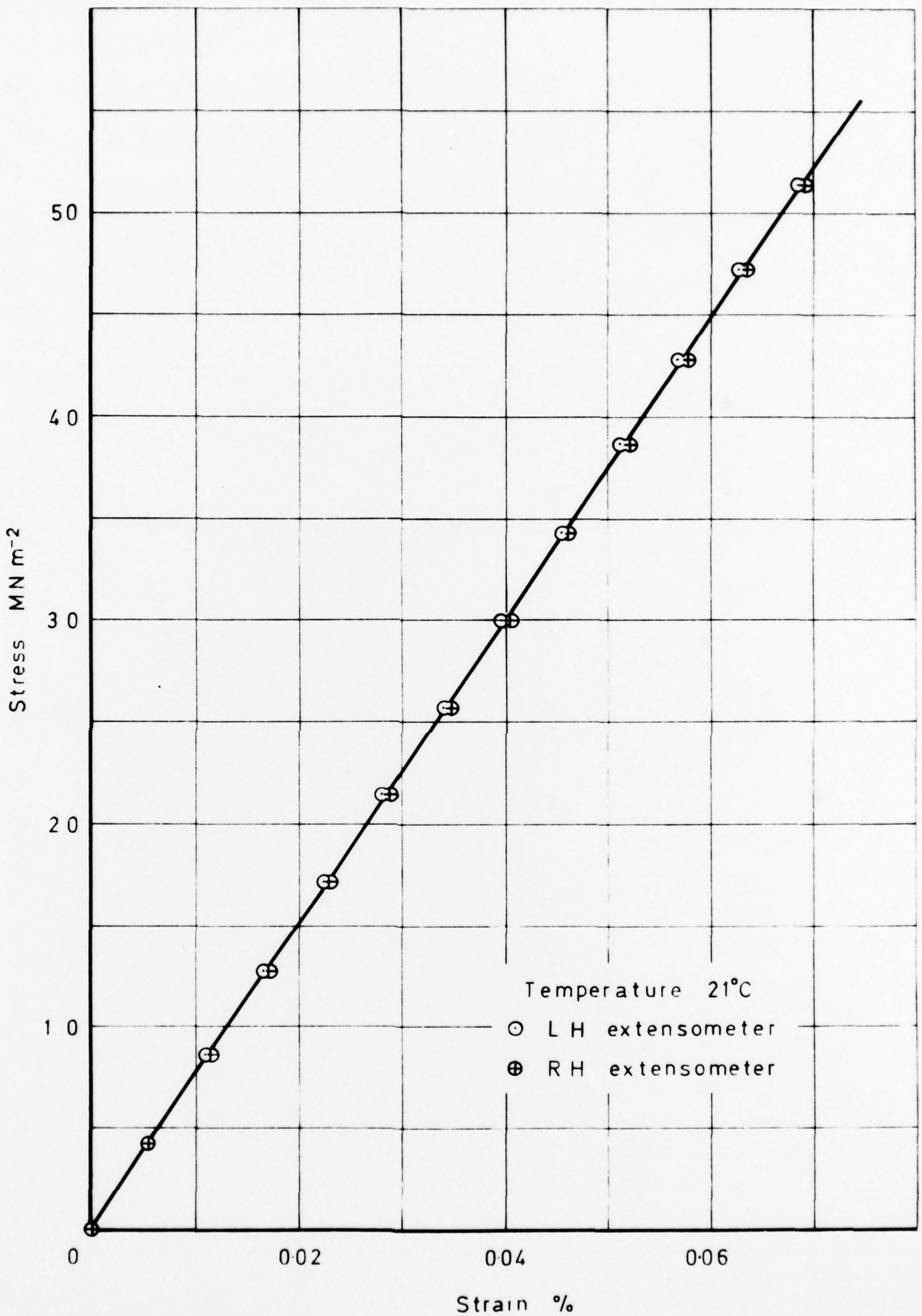

Fig.11 Typical incremental loading test — RE16

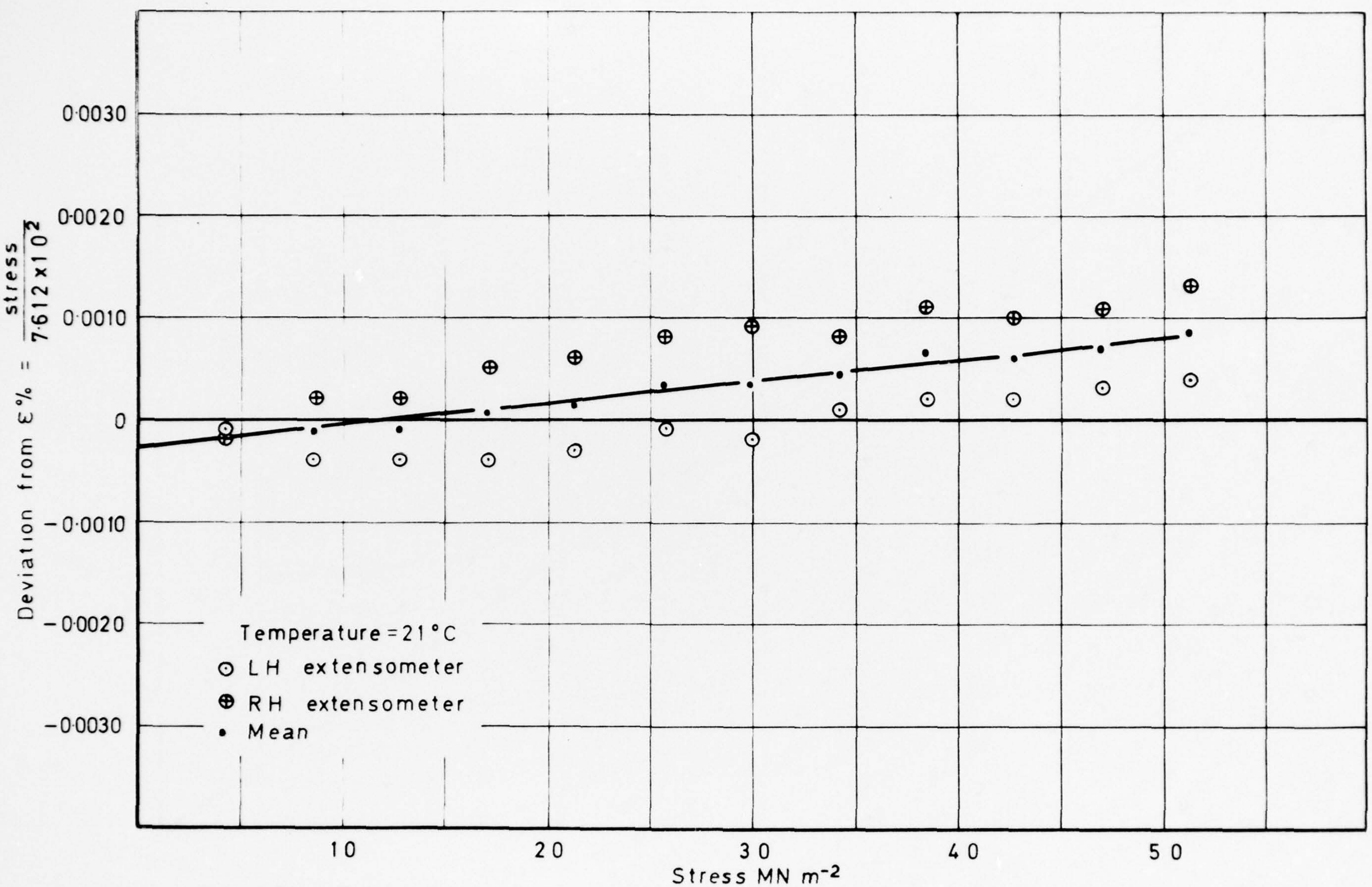

Fig.12 Typical incremental loading with aligned specimen: test — RE16

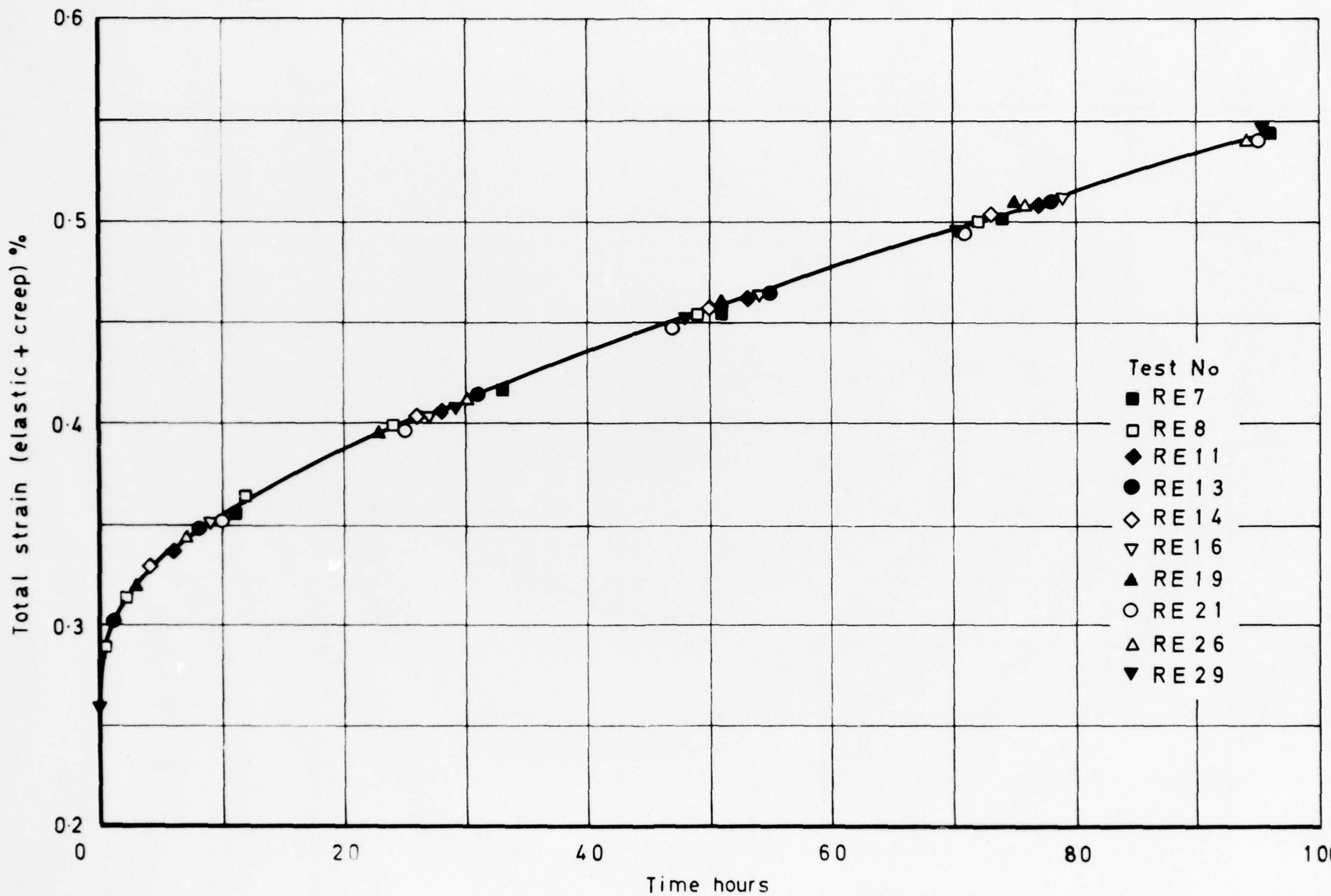

Fig.13 Creep repeatability —170 MN m^{-2} (11 ton in^{-2}) at 180°C

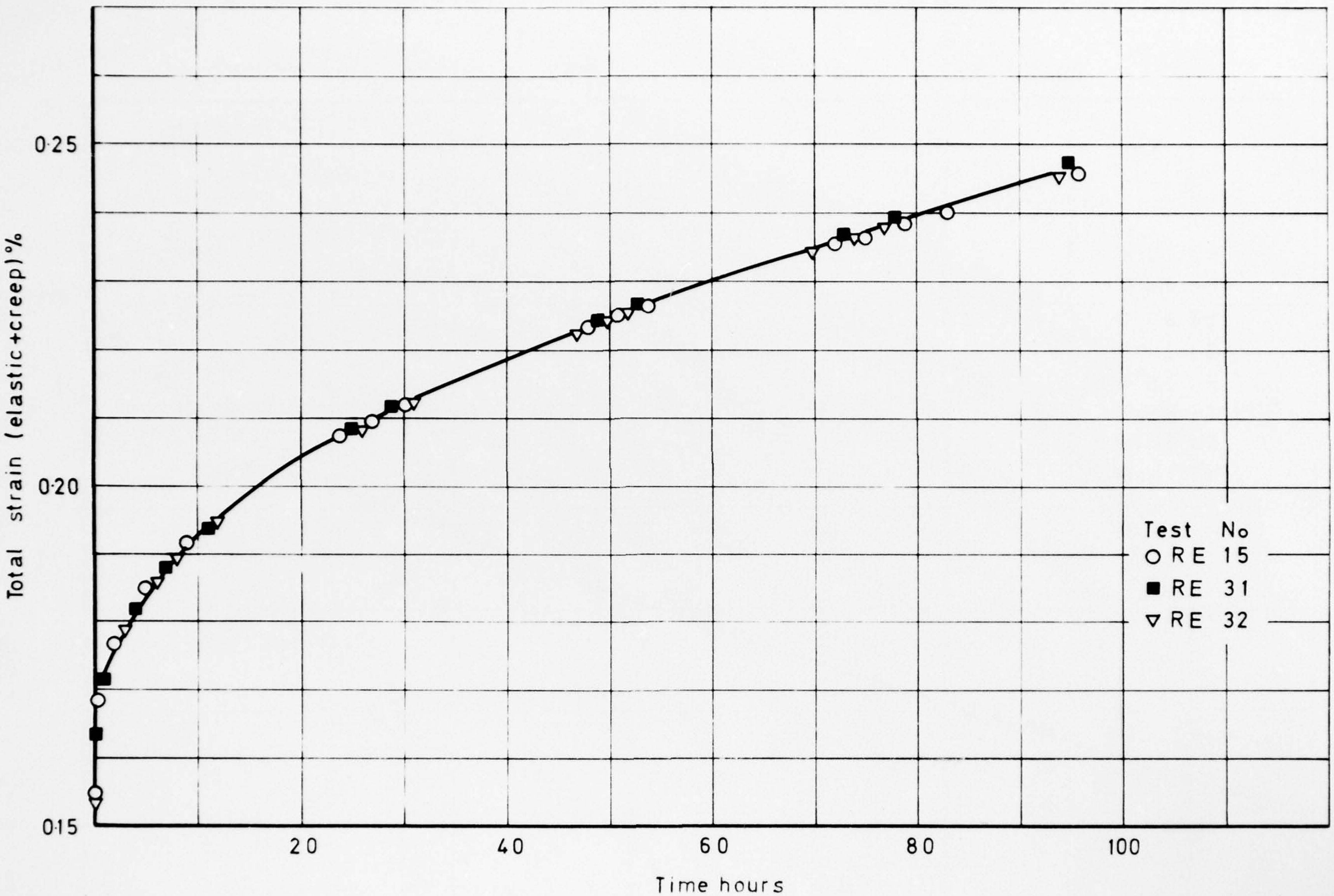

Fig.14 Creep repeatability —108·11 $MN.m^{-2}$ (7 $ton.in^{-2}$) at 180°C

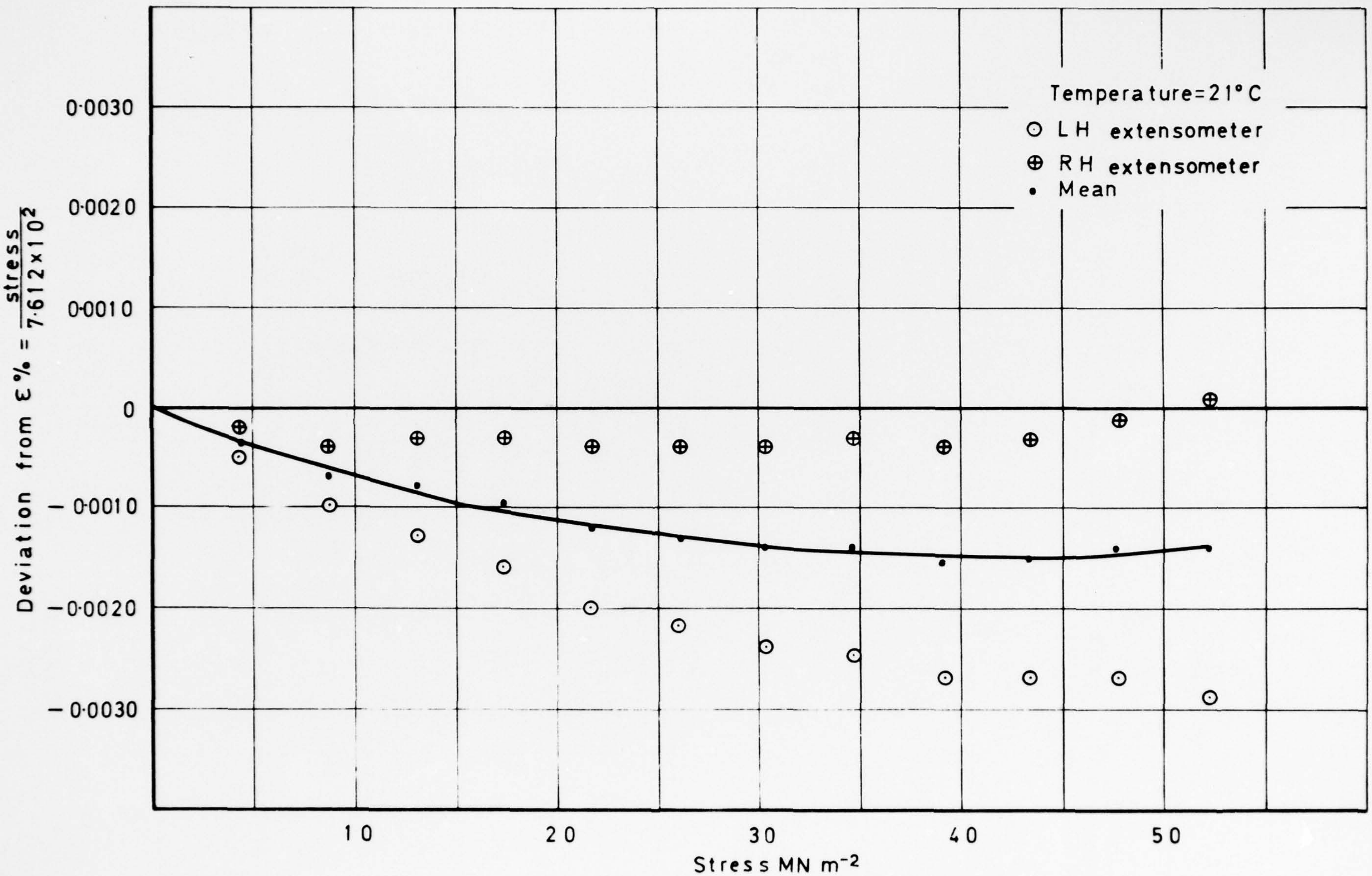

Fig. 15 Incremental loading with 0·0127mm (0·005in) lateral eccentricity — E1

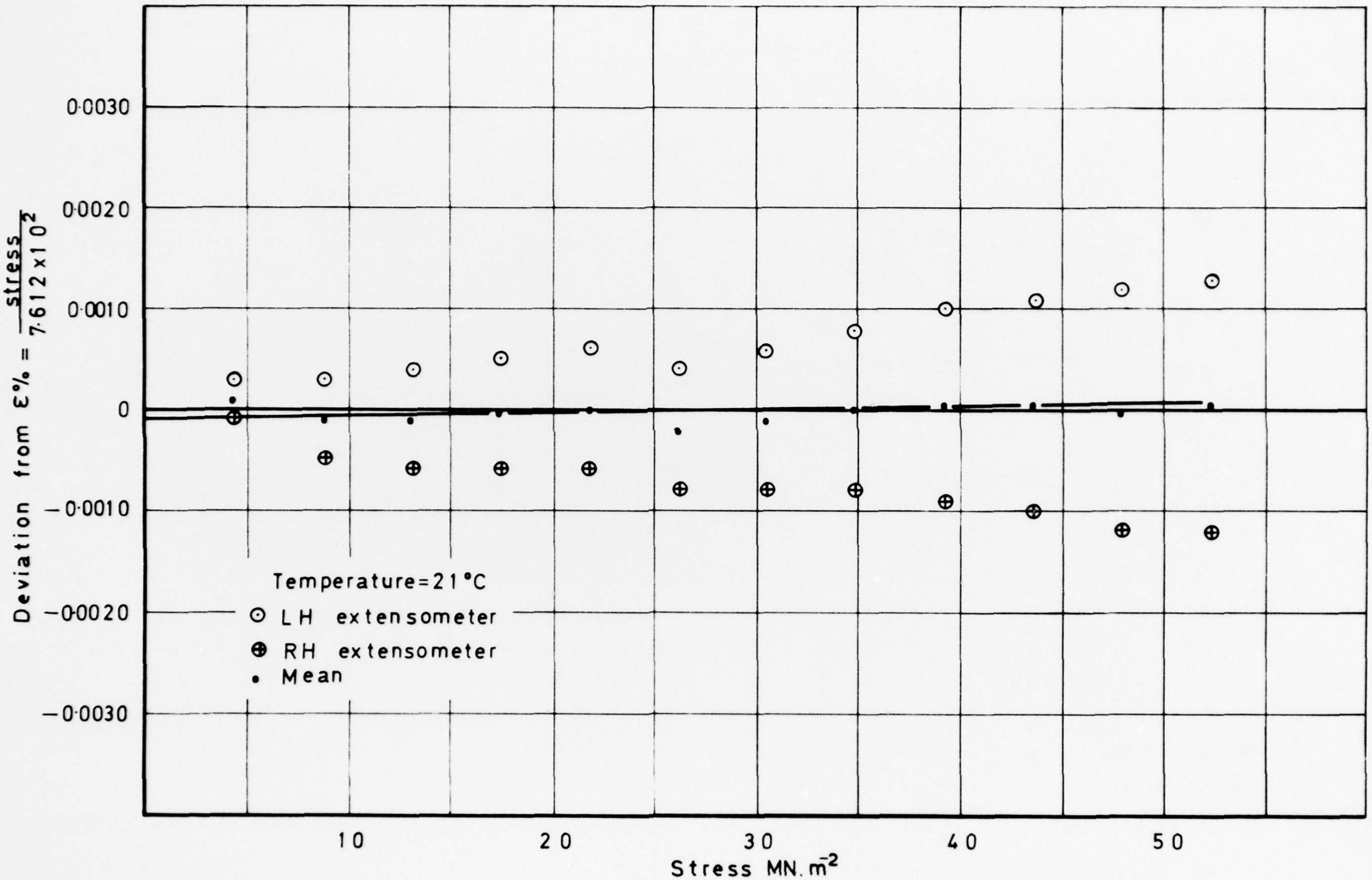

Fig. 16 Incremental loading with 0·0051mm (0·002 in) lateral eccentricity—E4

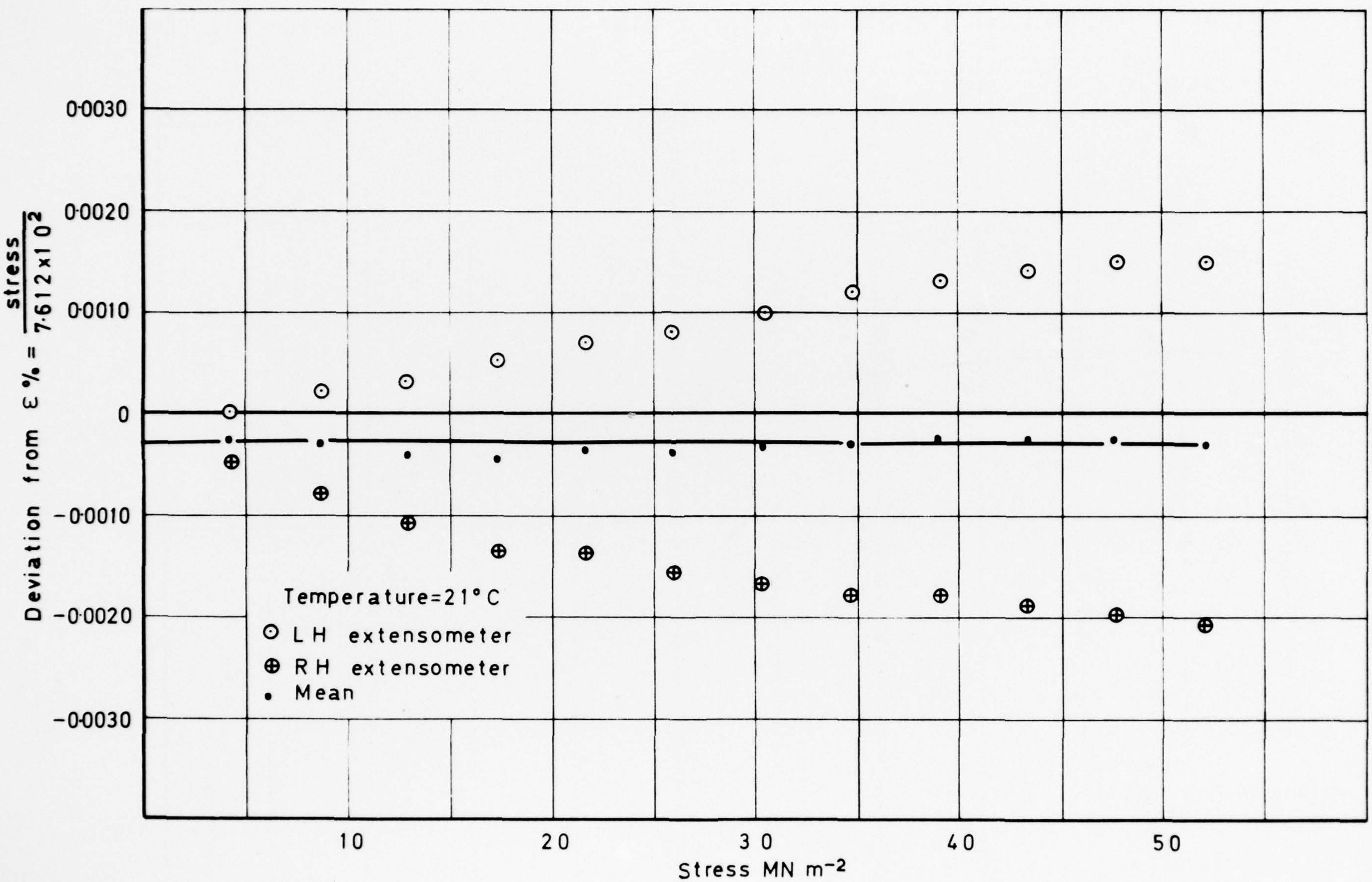

Fig.17 Incremental loading with 0·0051mm (0·002 in) lateral eccentricity — E5

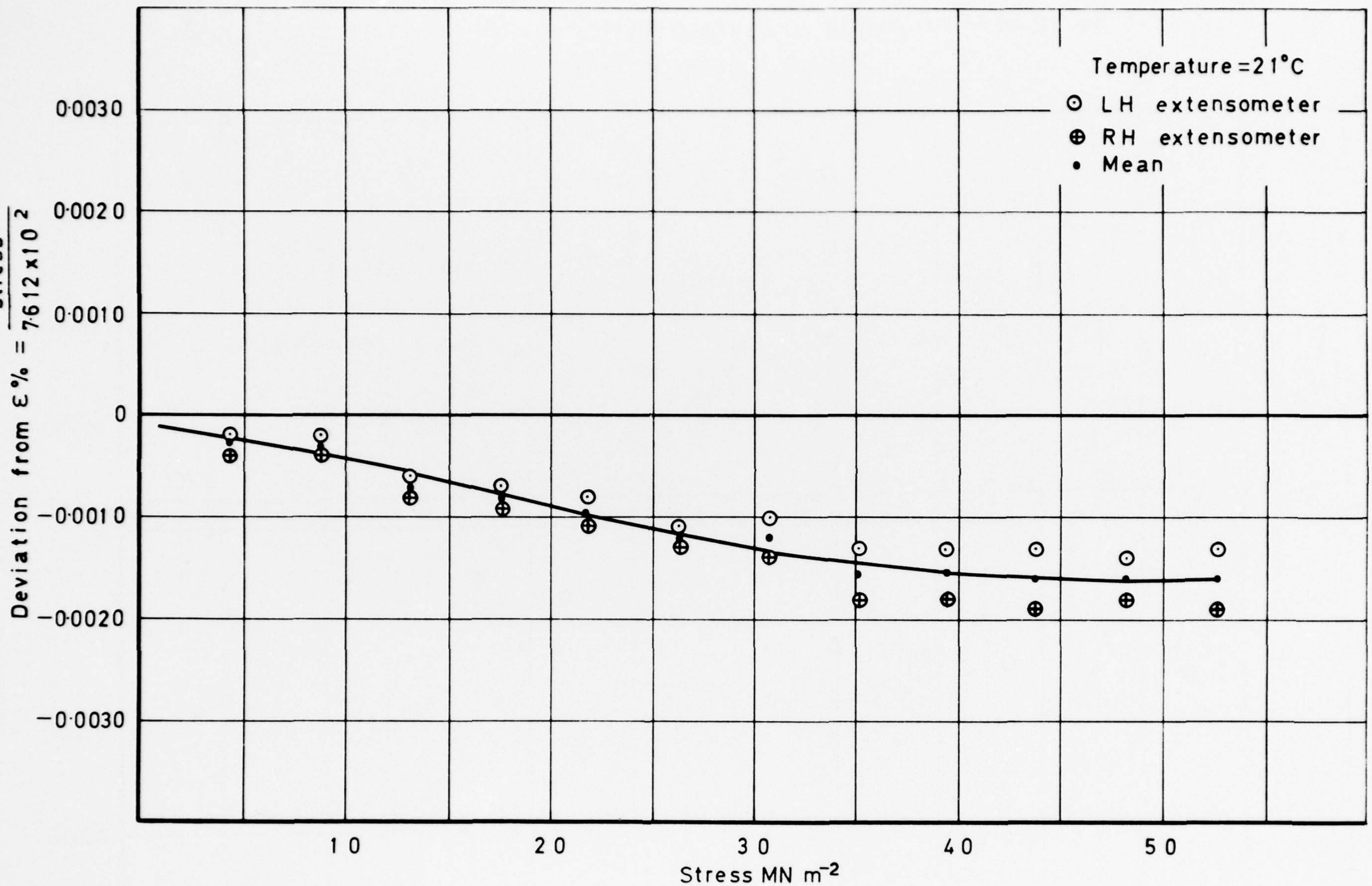

Fig.18 Incremental loading with ± 0·0127 mm (0·005 in) angular eccentricity—E 2

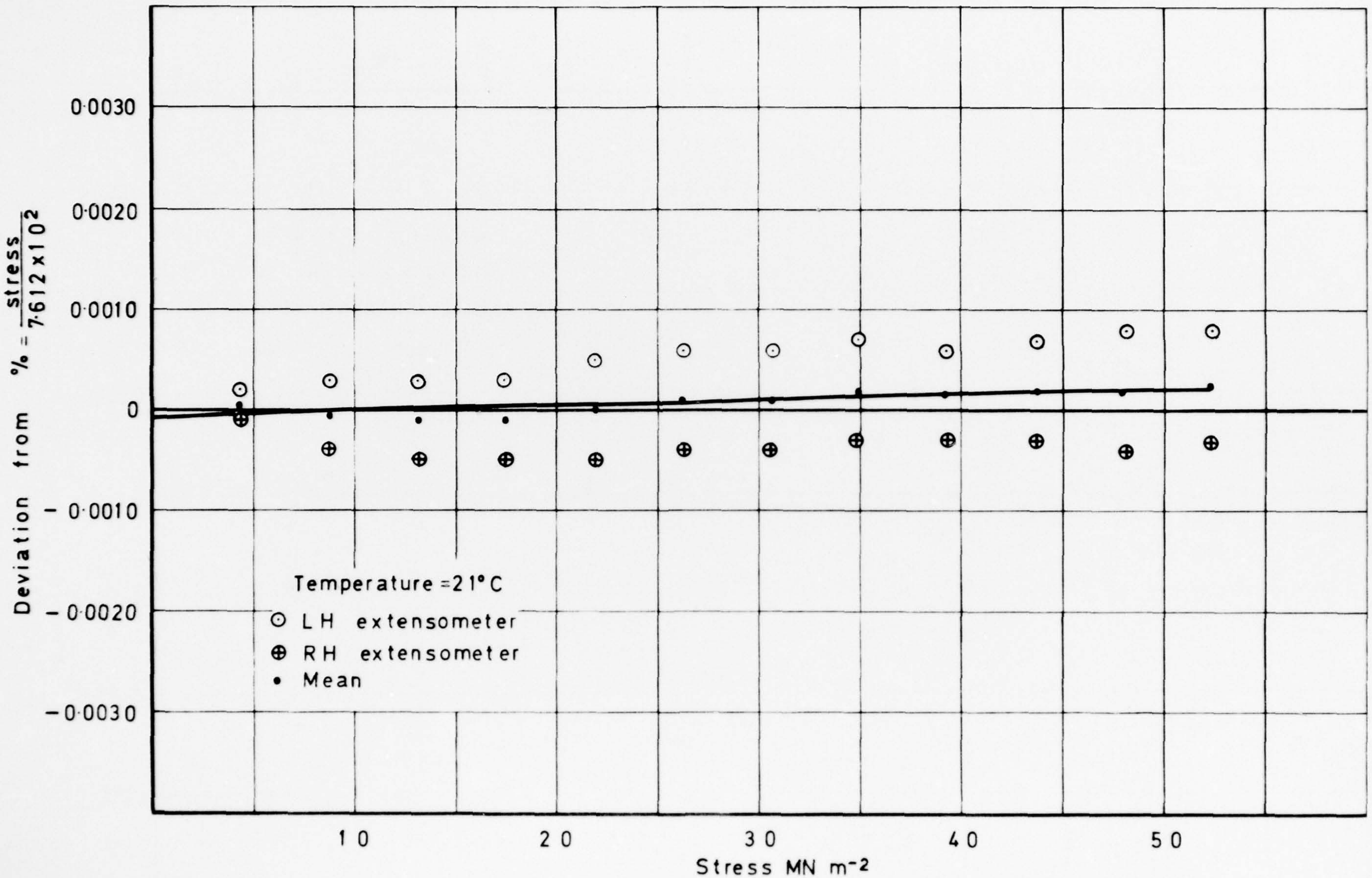

Fig. 19 Incremental loading with ±0·0051 mm (0·002 in) angular eccentricity — E3

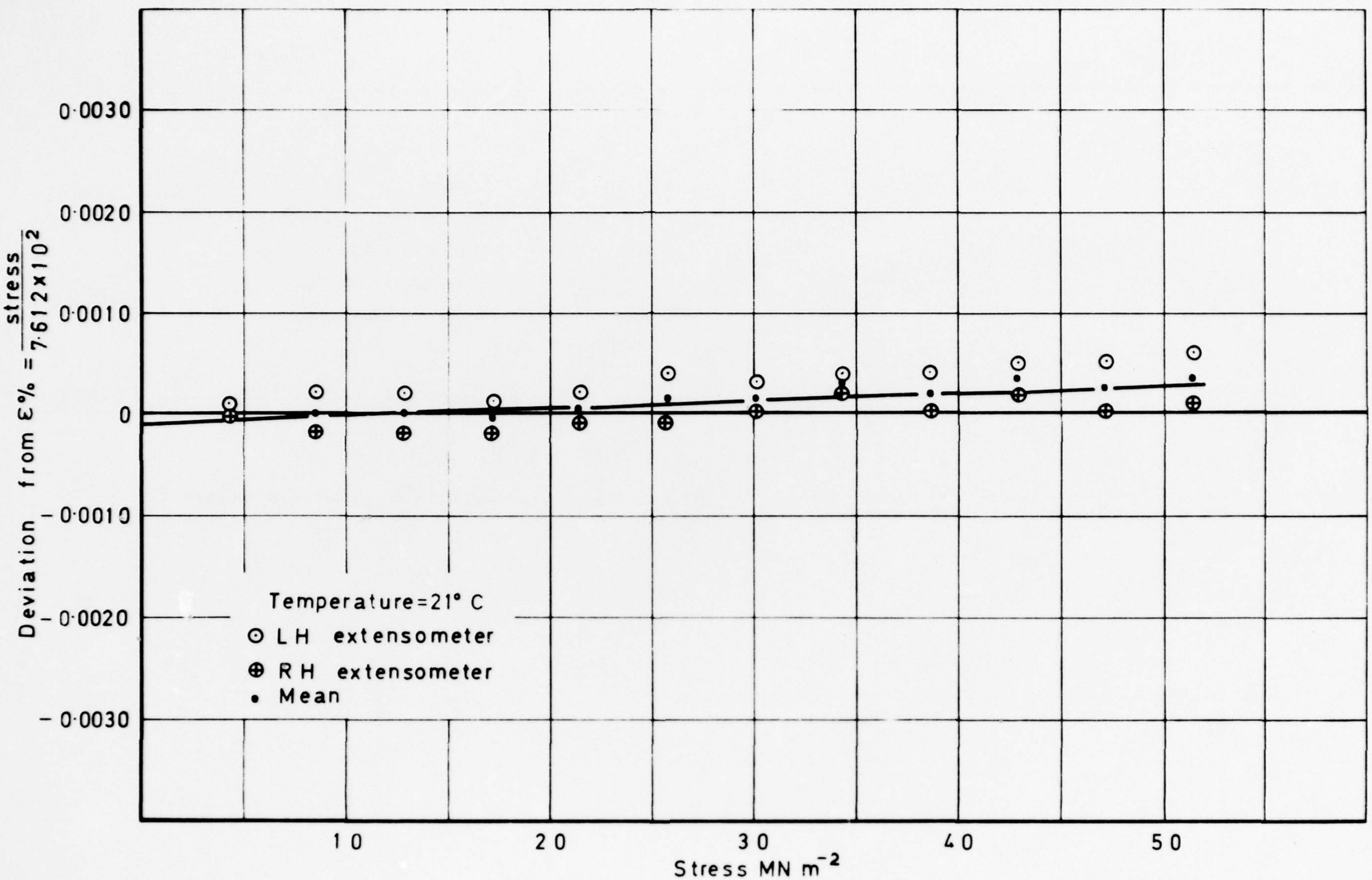

Fig. 20 Incremental loading with ±0 0051 mm (0·002 in) angular eccentricity–E6

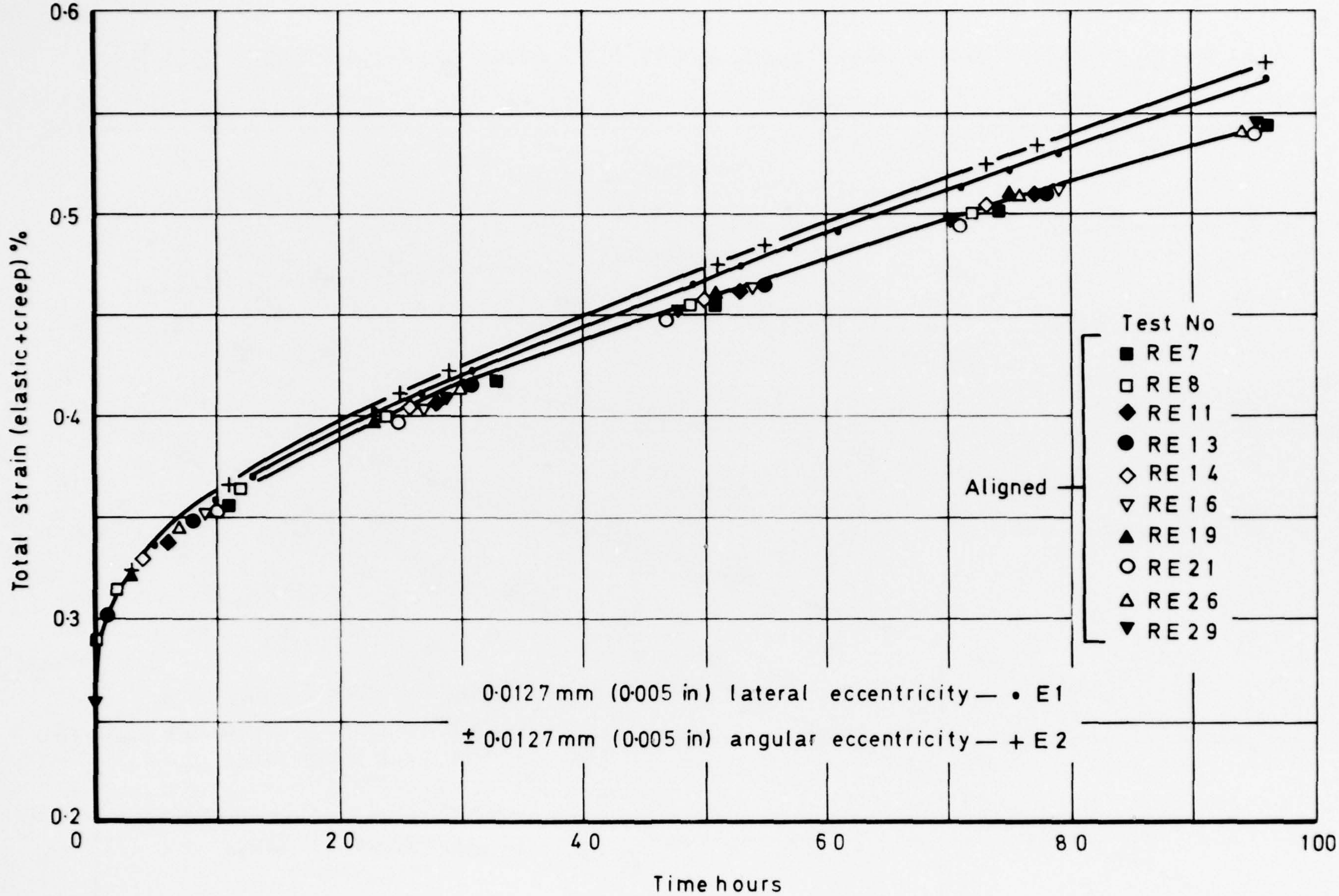

Fig. 21 Effect of eccentricity on creep strain — 170 MN m^{-2} (11 ton in^{-2}) at 180°C

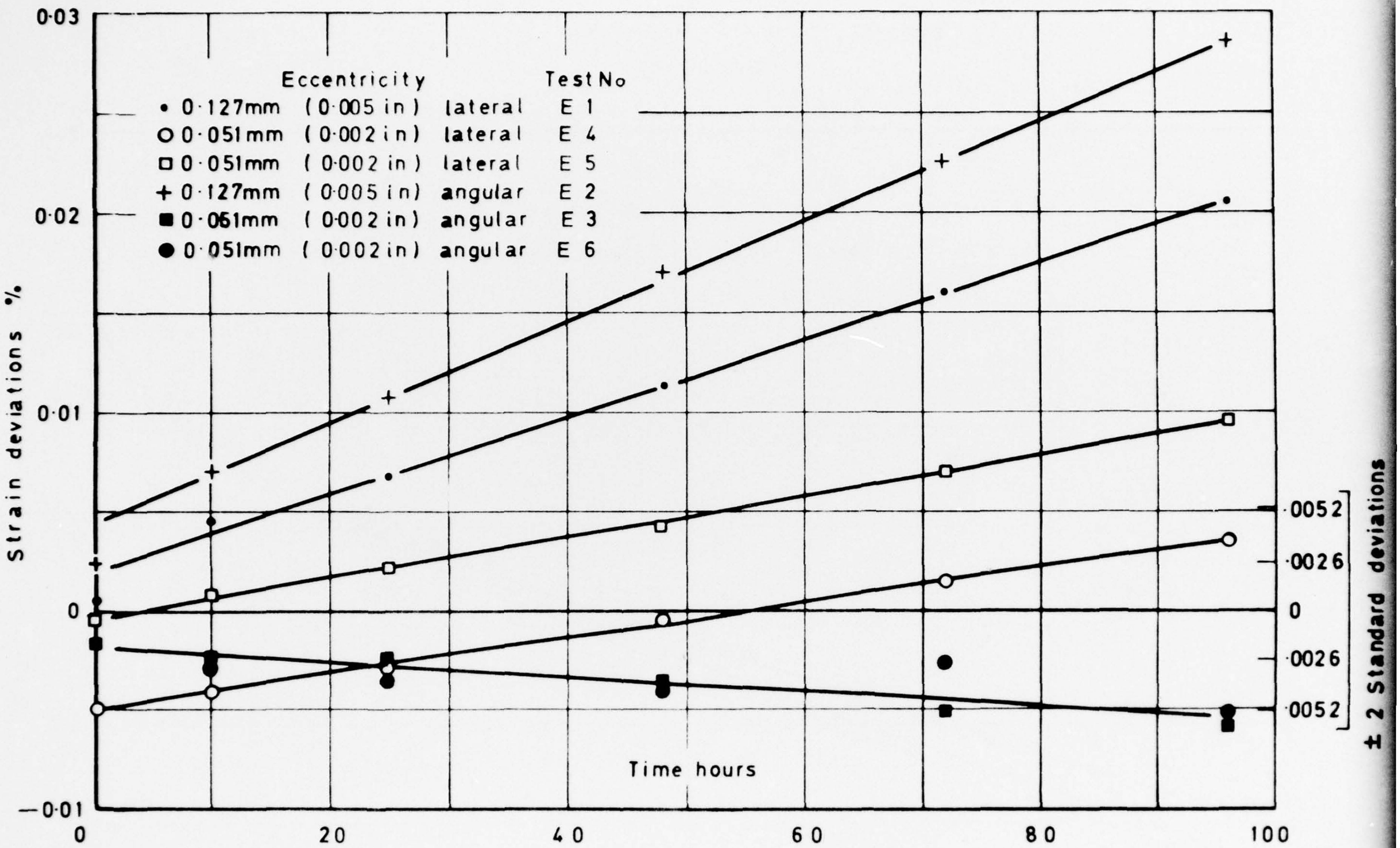

Fig. 22 Deviations of eccentric tests from mean creep curve—170 MN. m^{-2} (11 ton in^{-2}) at 180°C

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ARC CP No.1364
March 1976

620.172.25 :
620.171.2 :
620.1.052

Webb, J. N.

A SYSTEM FOR THE AXIAL LOADING OF CREEP SPECIMENS

The problem of eccentricity of loading is considered in relation to tensile creep testing. An alignment system has been developed to provide for the measurement and correction of the eccentricity of loading relative to the centre line of the test specimen. The repeatability of creep test data using this system over a period of several years is reviewed. Comparison with deliberately malaligned tests indicates that axiality of loading contributes significantly to the repeatability of creep testing.

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